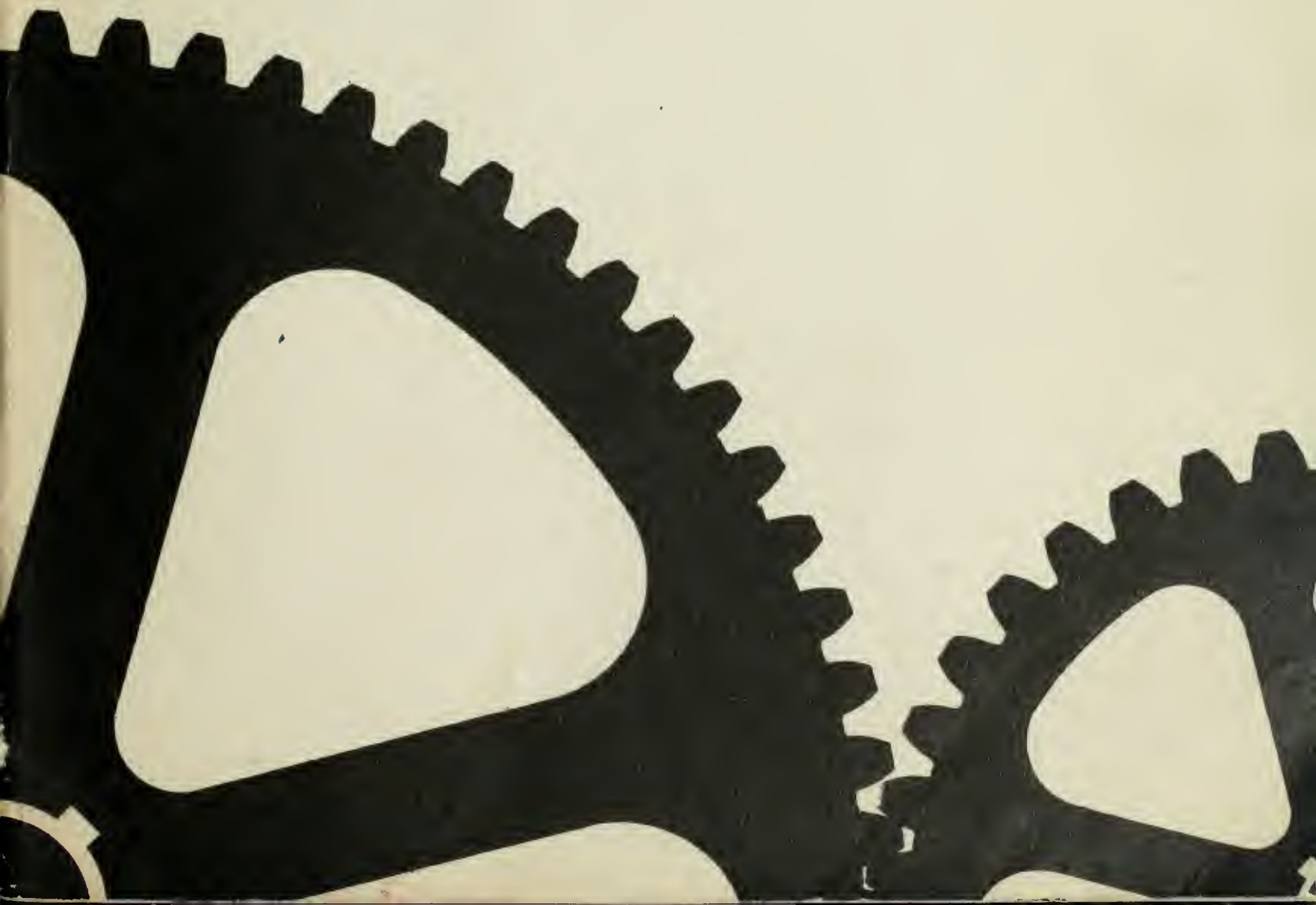
TECHNOLOGICAL TRENDS AND NATIONAL POLICY

JUNE 1937

NATIONAL RESOURCES COMMITTEE



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TECHNOLOGICAL TRENDS
AND
NATIONAL POLICY

INCLUDING THE SOCIAL IMPLICATIONS OF NEW INVENTIONS

JUNE 1937

REPORT OF THE

SUBCOMMITTEE ON TECHNOLOGY

TO THE

NATIONAL RESOURCES COMMITTEE

UNITED STATES GOVERNMENT PRINTING OFFICE WASHINGTON : 1937

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H. Con. Res. 21

CONCURRENT RESOLUTION

Resolved by the House of Representatives (the Senate concurring), That the Report of the Subcommittee on Technology, submitted to the National Resources Committee, entitled "Technological Trends and National Policy, Including the Social Implications of the New Inventions", be printed as a House document; and that ten thousand additional copies shall be printed, of which two thousand nine hundred copies shall be for the use of the Senate and seven thousand one hundred copies shall be for the use of the House.

Passed the House of Representatives July 22, 1937.

Attest:

South Trimble, *Clerk*.

In the Senate of the United States, June 22 (calendar day August 6), 1937.

Resolved, That the Senate agree to the foregoing Concurrent Resolution of the House of Representatives.

Attest:

E. A. Halsey, *Secretary*.

NATIONAL RESOURCES COMMITTEE
INTERIOR BUILDING
WASHINGTON

June 18, 1937.

The PRESIDENT,
The White House,
Washington, D. C.

MY DEAR MR. PRESIDENT:

We have the honor to transmit herewith a report on Technological Trends and Their Social Implications. Our Science Committee, including members designated by the National Academy of Sciences, the Social Science Research Council, and the American Council on Education, has prepared, through a special subcommittee headed by Dr. William F. Ogburn, the materials which comprise this report.

This document is the first major attempt to show the kinds of new inventions which may affect living and working conditions in America in the next 10 to 25 years. It indicates some of the problems which the adoption and use of these inventions will inevitably bring in their train. It emphasizes the importance of national efforts to bring about prompt adjustment to these changing situations, with the least possible social suffering and loss, and sketches some of the lines of national policy directed to this end.

Sincerely yours,

HAROLD L. ICKES
Secretary of the Interior, Chairman

HARRY H. WOODRING,
Secretary of War.

HENRY A. WALLACE,
Secretary of Agriculture.

DANIEL C. ROPER,
Secretary of Commerce.

FRANCES PERKINS,
Secretary of Labor.

HARRY L. HOPKINS,
Works Progress Administrator.

FREDERIC A. DELANO.

CHARLES E. MERRIAM.

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HENRY S. DENNISON.

BEARDSLEY RUML.

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ACKNOWLEDGMENTS

This report on Technological Trends and National Policy was instituted through the efforts of the Science Committee of the National Resources Committee. The Science Committee is composed of nine members, three each designated respectively by the National Academy of Sciences, Social Science Research Council, and the National Council of Education. The subcommittee on technology was constituted, consisting of William F. Ogburn, chairman, John Merriam, and Edward C. Elliott. This Committee appointed William F. Ogburn as director of research for the report. He was assisted by S. McKee Rosen.

The report could not have been prepared without the assistance of various universities, laboratories, and governmental bureaus. Acknowledgment and appreciation is due especially to the United States Department of Agriculture, United States Department of Commerce, United States Bureau of Mines, United States Government Printing Office, Federal Communications Commission, Federal Power Commission, Columbia University, the University of Chicago, Yale University, and Purdue University in making it possible for the contributors to aid in the preparation of the special reports in the volume. These various contributors have in turn been able to present their reports only with the cooperation of various individuals and institutions. Appreciation for these services is expressed in connection with the separate reports.

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FOREWORD

By the Science Committee

Anticipation of the future is the key to adequate planning for the best use of our national resources. It is, however, more difficult to look forward without the aid of precise instruments, than it is to look backward, with the aid of memory and records. Though this report attempts to deal with the future, it is fully realized that the future grows out of the past and hence that past trends must be studied to determine future trends.

Planning is usually carried on in relation to a specific task, for a definite time, in a limited territory; but changes coming from without these limits may upset the best laid programs. Thus the chemical inventions making substitutes of wool and cotton from cellulose, gasoline from coal, and rubber from coal and chalk, may affect cotton, coal, and timber production, and no doubt policies in regard to other natural resources. So closely interrelated is the mechanism of modern civilization that a change occurring in one part, say in industry, will produce an effect in a quite different and unexpected part, as for instance, in the schools, or the use of natural resources. Hence we need a view of the general causes, types, and trends over a broad front, since any specific program may be affected by forces originating elsewhere.

Invention is a great disturber and it is fair to say that the greatest general cause of change in our modern civilization is invention; although it is recognized that social forces in turn encourage or discourage inventions. Certainly developments in technology cause a vast number of changes in a great variety of fields. A banker once defined invention as that which makes his securities insecure. Hence a study of the trends of inventions furnishes a broad perspective of many great movements of change and basic general information for any planning body, however, general or specific their plans may be.

The Nature of the Report

This report presents a survey of most of the great fields of technology and applied science, namely, agriculture, mining, transportation, communication, the construction industries, power production, the metallurgical and chemical industries, and the electrical manufactures. Chapters on these subjects comprise part III of the report. The purpose is to cover a wide range; for the specialization so necessary for progress needs to be accompanied by broader vision. It was possible to obtain this wider perspective by dealing only with the more significant inventions. Since inventions were selected for this report on the basis of their social significance, omissions are important as truly as inclusions, especially as the surveys were conducted by competent authorities in the different fields.

It has been thought best to focus on the near future, which is defined as the next 20 years; but any blinders that cut off sharply the present, the more distant future, or even the recent past, would mean an inadequate investigation, since change is a process.

Most planning is not concerned with invention as such, but with the effects of inventions. These social effects come only after widespread use, which may follow long after the patent has been granted. Thus, telephoning for considerable distances has been possible for some time; but it is only in the future that the volume of long distance telephoning will be sufficiently large to have much effect on the relationship of location of residence to location of business, or upon the growth of suburb and village. Some inventions that are already highly developed today are reported in the pages that follow since the influences they precipitate will be occurring in the near future. Still more recent inventions will also have influences in the immediate future. The air conditioning developments which lower inside temperatures during hot weather may or may not within the next generation affect southern cities and stimulate the growth of factories in warmer regions. Or again, tray agriculture, which produces a high yield per plant when the roots are suspended in a tray of liquid chemicals instead of in the soil, may or may not be used sufficiently to be of much social significance within the reader's lifetime. The particular social influences which the inventions here surveyed may have are indicated in many cases by the authors of the chapters in the third part of the report.

Part I of the report is devoted to the social aspects of technology and its relationship to planning in a series of selected topics of special importance, such as technological change and unemployment or resistances to the adoption of inventions. Throughout the report, then, there will be found discussions of the effects of inventions on society, although the many different effects are difficult to foresee. In the case of the airplane, for example, few persons even at the time of the World War foresaw the present influences of the bomber on international relations. There is as yet no science capable of predicting the social effects of inventions and decades will be required for such

a development. Until that time each planning unit of government or industry will try to predict the future by drawing its own conclusions as to possible influences of inventions, known and foreseeable.

Findings

1. The large number of inventions made every year shows no tendency to diminish. On the contrary the trend is toward further increases. No cessation of social changes due to invention is to be expected. It is customary to speak of the present age as one of great change, as though it were a turbulent transition period between two plateaus of calm, but such a conclusion is illusory. Though the rate of change may vary in the future there is no evidence whatever of a changeless peace ahead.

2. Although technological unemployment is one of the most tragic effects of the sudden adoption of many new inventions (which may be likened to an immigration of iron men), inventions create jobs as well as take them away. While some technological changes have resulted in the complete elimination of occupations and even entire industries, the same or other changes have called into being new occupations, services, and industries.

3. No satisfactory measures of the volume of technological unemployment have as yet been developed, but at least part of the price for this constant change in the employment requirements of industry is paid by labor since many of the new machines and techniques result in "occupational obsolescence." The growth and decay of industries and occupations caused by technological progress necessitate continuous and widespread—and not always successful—readjustments and adaptations on the part of workers whose jobs are affected by these changes.

4. The question whether there will be a large amount of unemployment during the next period of business prosperity rests only in part on the introduction of new inventions and more efficient industrial techniques. The other important elements are changes in the composition of the country's production (such as appreciable changes in the proportion which service activities constitute of the total), the growth of population, changes in the demands for goods and services, shift in markets, migration of industry, hiring age policies of industries, and other factors discussed in the body of the report.[1] For instance, even if industrial techniques remained the same, the volume of production would have to be greater in the future than in 1929 in order to absorb the increase in the working population and keep unemployment to the level of that date. If the productivity of 1935 (the latest year for which figures are available) continues the same in 1937, and the composition of the nation's total product remains unchanged, production would have to be increased 20 percent over that of 1929 to have as little unemployment as existed then. Failing this there will be more unemployment and if labor efficiency is increased by new inventions or otherwise, then the production of physical goods and services must be more than 120 percent of what it was in 1929.

5. Aside from jobs, subtracted or added, new inventions affect all the great social institutions; family, church, local community, State, and industry. The Committee finds that in all the fields of technology and applied science which were investigated there are many new inventions that will have important influences upon society and hence upon all planning problems. Particularly impressive were new inventions in agriculture, communication, aviation, metallurgy, chemistry, and electrical tools and appliances.

6. A large and increasing part of industrial development and of the correlated technological advances arises out of science and research. Invention is commonly an intermediate step between science and technological application, but this does not make less important the point that the basic ideas upon which these programs are developed come out of scientific discovery or creative activity.

7. Advance of many aspects of industry and the correlated technologies is dependent upon scientific research and discovery. This fact is made clear by the increasing importance of research laboratories in the great industries. The research conducted is not only well organized but it is carried forward with the cooperation of investigators having high rank in the field of science. If the contribution of research were to be reduced, the industries would tend to freeze in a particular pattern.

8. Though the influence of invention may be so great as to be immeasurable, as in the case of gunpowder or the printing press, there is usually opportunity to anticipate its impact upon society *since it never comes instantaneously without signals.* For invention is a process and there are faint beginnings, development, diffusion, and social influences, occurring in sequence, all of which require time. From the early origins of an invention to its social effects the time interval averages about 30 years.

9. While a serious obstacle to considering invention in planning is lack of precise knowledge, this is not irremediable nor the most difficult fact to overcome. Other equally serious obstacles are inertia of peoples, prejudice, lack of unity of purpose, and the difficulties of concerted action.

[1] See pt. 1, sec. 5.

10. Among the resistances to the adoption of new inventions and hence to the spread of the advantages of technological progress there is specially noted those resistances arising in connection with scrapping equipment in order to install the new. Better accounting methods and greater appreciation of the rate of inventional development facilitate the spread of improved capital goods. The rate of capital obsolescence is especially a major problem under monopolistic conditions, which probably favor the adoption of technological improvements less than do conditions of keen competition.

11. The time lag between the first development and the full use of an invention is often a period of grave social and economic maladjustment, as, for example, the delay in the adoption of workmen's compensation and the institution of "safety first" campaigns after the introduction of rapidly moving steel machines. This lag emphasized the necessity of planning in regard to inventions.

Recommendations

1. The reports herewith presented reveal the imminence of a few very important inventions that may soon be widely used with resultant social influences of significance. Since these inventions may deeply affect planning it is recommended that a series of studies be undertaken by the planning agencies herein recommended or by existing planning boards, with the aid of such natural and social scientists as may be needed, on the following inventions: the mechanical cotton picker, air conditioning equipment, plastics, the photoelectric cell, artificial cotton and woolenlike fibres made from cellulose, synthetic rubber, prefabricated houses, television, facsimile transmission, the automobile trailer, gasoline produced from coal, steep-flight aircraft planes, and tray agriculture.

2. A special case of the influence of invention is technological unemployment. It is recommended that a joint committee be formed from the Department of Labor, the Department of Commerce, the Department of Agriculture, Bureau of Mines, Interstate Commerce Commission, Social Security Board, and the Works Progress Administration with such other cooperation as may be needed, for the purposes of keeping abreast with technological developments and ascertaining and noting the occupations and industries which are likely to be affected by imminent technological changes and the extent to which these inventions are likely to result in unemployment. It is recommended that such information be made available through the appropriate departments to the industry and labor likely to be affected.

3. In view of the findings regarding the importance of technology and applied science, it is recommended that the Federal government develop appropriate agencies for continuous study of them; and more specifically that there be set up in the respective departments science committees with the definite function of investigating and reporting at regular periods on the progress and trends of science and invention and the possible and economic effects flowing therefrom as they affect the work of the departments and of the agencies to whom they render service. Copies of such reports should be supplied to the National Resources Board and it is recommended that insofar as is feasible they be made available to the various city, county, and State planning boards, and to the public.

4. Since the patent laws have considerable influence on the rate of technological progress, it is recommended that the whole system be reviewed by a group of social scientists and economists. This review, unlike others dealing with specific reforms, technical operations, scientific aspects, or ethical implications should be concerned with the articulation of the patenting process with the fundamental processes of human progress and the types of economic systems. From such basic relationships the better adaptation of the system to changing conditions can be worked out in the necessary detail.

5. It is recommended that the Science Committee of the National Resources Committee, with the cooperation of other scientists that may be needed, make an investigation of the adequacy of the reporting of inventions and of discoveries in applied science and advise on the feasibility (*a*) of more balanced coverage, (*b*) of selecting those more socially significant, and (*c*) of assembling of such data in some central location or locations.

6. The most important general conclusion to be drawn from these studies is the continuing growth of the already high and rapidly developing technology in the social structure of the Nation, and hence the hazard of any planning that does not take this fact into consideration. This pervasive interrelationship so clearly manifest throughout the pages of this report points to one great need, namely, a permanent over-all planning board. Such a board is needed to give breadth of consideration to the variety of factors which affect specific plans. This board would take its place in the governmental pattern as coordinator for the many special planning boards, of which there are now 47 State boards, 400 county boards, and 1,100 city boards. The Technology Committee, therefore, makes to the National Resources Committee, as a major recommendation of this report, the creation of a National Resources Board, as recommended by the President's Committee on Administrative Management in their report of January 8, 1937.

PART ONE
SOCIAL ASPECTS OF TECHNOLOGY

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I. NATIONAL POLICY AND TECHNOLOGY

By William F. Ogburn [1]

When conditions are changing rapidly, policies for national welfare are especially in need of guiding principles. To this end, knowledge of probable technological trends is, in modern times, of very great help. This idea which is the subject of this section of the report of the National Resources Committee may be set forth briefly in a paragraph.

In an age of great change, anticipation of what will probably happen is a necessity for the executives at the helm of the ship of state. A study of invention offers a very good clue to future social conditions and problems of a nation. For, of four material factors that determine the economic well-being of nations, to wit, invention, population, natural resources, and economic organization, the first changes the most frequently in the modern world and hence is most often a cause. Thus, there are 50,000 patents a year and some of them have great influence. For instance, the airplane will change the nature of national defense in case of war. In this case the growth of the airplane precedes the development of national defense. This sequence is common. The scientific achievement comes first and the social effects later. The fact that there is a lag makes invention a social barometer. The production curve of automobiles forecasts the growth of suburbs. Furthermore, since it requires a quarter of a century more or less for an invention to be perfected and to be put into wide use, it is possible to anticipate their results some years ahead. Whether the social effects of inventions can in practice be read off this barometer with sureness is doubtful in the present stage of the advancement of social science. But that inventions are an indicator seems clear though it may require special education so to use them. The usefulness of scientific discovery as a guide for national policy is also strengthened because of (*a*) the great variety of inventions and (*b*) the number of points of contact between a modern government and the affairs of its citizens. It follows, then, that whether plans are made and executed or not, trying to anticipate is an endeavor of prime importance, unless drifting is to be the course.

These conclusions were at the basis of the recommendations of the President's Research Committee on Social Trends appointed by President Hoover in the autumn of 1929 and which reported their findings 3 years later in their report, Recent Social Trends. In discussing the vast complexity of problems that confront our Nation, that committee found "* * * that the clue to their understanding as well as the hope for improvement lies in the fact of social change. Not all parts of our organization are changing at the same speed, or at the same time. Some are rapidly moving forward and others are lagging. These unequal rates of change in economic life, in government, in education, in science and religion make zones of danger and points of tension * * *. Scientific discoveries and inventions instigate changes first in the economic organization and social habits which are most closely associated with them * * *. The next set of changes occurs in organizations one step further removed, namely, in institutions such as the family, the government, the schools, and the churches. Somewhat later as a rule come changes in social philosophies and codes of behavior * * *."

Thus the analysis in the Committee's report, which is here quoted because of its significance for national policies, was based upon a recognized lack of balance in civilization occasioned by unequal rates of change in the different parts of the social organism, beginning in point of time with mechanical invention and scientific discovery. Thus invention and discovery become guides to future changes, though, of course, not the only ones; nor are they infallible.

This report of the National Resources Committee then begins where the President's Committee on Social Trends left off. The development proceeds from this point in the sections which follow.

Great Inventions and Progress in the Twentieth Century

The significance of technology for economic and social life may be shown by considering certain developments of the twentieth century. Only 35 years have elapsed since the beginning of the century, during which time the Nation has experienced a phase of unparalleled development. Most of the Members of the present Congress had at that time finished school and college, and were already launched on the career that was to place them among the policy-makers of the Nation. It would have been enlightening for them to have looked ahead then at the probable course of technology. A scanning of the technological horizon at that time would have revealed the beginnings of several of our largest industries, based upon inventions then relatively new.

[1] Professor of Sociology, University of Chicago.

For instance, there were not many telephones in use in 1900, around a million in number. Yet the telephone industry was destined to grow into the third largest public utility in the United States, with an investment of nearly $5,000,000,000 and giving employment to hundreds of thousands. Its influence has been far reaching. It broke the isolation of the farms, increased the number of business transactions, and speeded the tempo of modern life. Its importance to special industries, such as newspapers, has been of inestimable value. It has tended to break down State lines, to eradicate regional differences, and to increase international contacts. It has been of aid in safety, in transportation, in fighting fires, and crime.

The automobile was just coming into use in 1900, as is illustrated by the newspaper comments of the time commending Theodore Roosevelt for his "characteristic courage", when he rode in an automobile. Thirty-five years later there is one automobile to every five persons in the United States. The automobile has had a profound effect on cities. Just as the railroads caused cities to spring up all over the country, so the automobile is changing them, hurling their population with a centrifugal force outward into the suburbs and drawing into an ever-widening trading area many millions of inhabitants drawn from remoter regions. Thus it has created a new unit of population neither city, town, nor hamlet, for which there is as yet no name, but which is often referred to as a metropolitan area. As the railroad built up the big city, so the truck is helping to build up the small place within the metropolitan area. Some metropolitan areas have many hundreds of different governmental units when one or at least a few would make many economies and produce efficiencies impossible in small units. In addition, the gas engine has brought the industrial revolution to the farm, has been of great aid to the criminal, and has become an engine of death to thousands of the people every year. There is therefore reason to the remark that the inventors of the automobile have had more influence than Caesar, Napoleon, and Ghengis Khan.

Most of the present Members of Congress did not go to moving-picture shows as children, for there were none for them to attend. This is probably no matter of regret, but it meant that they had little opportunity to speculate on the future of this industry which today in the United States draws every 10 days patrons equivalent in number to the whole population, a truly marvelous growth within a quarter of a century. This great industry, like that of the telephone and the automobile, has helped to knit the territory together in a psychological sense, for the entire population is now exposed to the same stimuli, which brings them news, tells them the same stories, familiarizes them with the same types of manners and morals and hence opens up a new agency of education and propaganda. Florida sees the same moving pictures as Oregon; the farmer learns better than before the ways of a city. A great new competition for leisure time arose, affecting home, church, and school. It was difficult to foresee these consequences in 1900.

The airplane was not taken seriously at that time. Simon Newcomb, dean of science, wrote in 1903: "May not our mechanicians be ultimately forced to admit that aerial flight is one of that great class of problems with which man can never hope to cope and give up all attempts to grapple with it?" That passengers would be flown across the Atlantic Ocean to Europe was not contemplated. Nor was it envisioned that a thousand enemy airplanes of the bomber type could swoop down on a city and utterly destroy it, with hardly an effective gesture of defense on the part of the helpless inhabitants. Clearly the airplane has brought about changes that affect the functions of both Congress and the Chief Executive.

Other inventions have been developed since the beginning of the century which have influenced public policy less directly, but yet effectively. It is reported that a visitor came to this country recently from the land of Aladdin, who, according to all accounts, possessed a wonderful lamp that could do truly miraculous things such as transporting a person from one city to another on a rug or creating a ship full of jewels. This visitor, though nurtured on tales so stimulating to the imagination, was truly astounded when he saw factories in the United States where a wooden box was turned into a pair of silk stockings, where a lump of coal yielded colors more beautiful than royal purple and perfumes more delicate than attar of roses. Rayon has blurred lines between the social classes, once looked upon as barriers that were beginning to form even in the homeland of Andrew Jackson. Perhaps more impressive, this chemical product with other influences has helped to imperil a cotton kingdom and a textile industry which brought on the industrial revolution, and clothed the world with cotton garments.

The development of the radio, unheralded in 1900, must have appeared equally miraculous to the visitor from the East when he heard a man at the South Pole talking through the air to hundred of thousands of listeners in continents separated by oceans. The radio broadcast has affected profoundly public policies, since it is an agency of unparalleled power for propaganda. But it has influenced the lives of the people more by bringing them recreation and education with dramatic ease, especially in the relatively isolated farms and villages.

There are other industries built on inventions that have been developed since the beginning of the century. But these six industries based on the telephone, the automobile, the airplane, the motion picture, rayon, and the radio represent great accumulations of capital and give employment to millions, besides having had social influences so vast in number and extent as to be impossible to calculate.

If the Legislators, Governors, and Presidents since the beginning of the century could have foreseen the development of these six great industries and could have anticipated their influence on society and the changes precipitated, they would have been in a much better position for directing the policies of the State. Highways are too narrow. The metropolitan area could have been planned better; much crime could have been prevented. Industries could have been located to greater advantage. The growing inadequacies of small local governments could have been more clearly foreseen, and the transfer of some of their functions to a more capable centralized government would have been facilitated. In hundreds of ways the governments, industries, and individuals could have planned more soundly.

What has been written in the preceding paragraphs is past history. This is 1936 and not 1900. The Nation does not stand on the threshold of a new century. But progress is not confined to calendar arrangement. A new hundred years begins at any time. The question that naturally arises is, Will the second third of the twentieth century see the rise of such great industries based on new inventions as was seen in the first third? There may very well be six equally significant inventions during the next phase of our national growth as in the one just concluded.

For instance, all are agreed that one such invention is the electron tube, said to be the greatest invention of the twentieth century. Its most brilliant form is the photoelectric cell, popularly known as the electric eye. This eye sees everything that the human eye can see and more. It is even said to be able to detect certain types of counterfeit money. It will distinguish colors better than human beings can do. When it is joined with another form of the electron tube, the vacuum tube, it becomes able to act on what it sees. Thus it sees a waitress approaching a door with trays in both hands and at once swings the door open for her to pass. Unlike a human being it does not suffer from fatigue. For instance, in a factory it can watch the tin cans go by on a belt, pick out the defective ones, letting only the good ones go by. This monotonous work can be done without strain for as long hours as the manager wishes. That it will cause unemployment is obvious, but it will also lighten the tasks of the workmen. Indeed it brings the automatic factory and the automatic man one step closer. It may be used to regulate automobile traffic, to measure the density of smoke, to time horse racing, to read, to perform mathematical calculations. Hardly a month passes without some new use of the photo-electric cell being reported. Indeed it will require decades to learn the many things this versatile instrument can do.

There are other such new inventions described in the chapter which follow—inventions which will carry the Nation on to even greater achievement during the years to come. But it should be remarked here that the changes of the future do not rest wholly on these new inventions. While the six inventions mentioned in previous paragraphs are past history, their social effects are by no means all past. Many of these inventions will continue to precipitate problems of policy for the Congressmen yet to come. The full effects of artificial fibers have not yet been felt. The influence of the airplane has just begun. Even the familiar telephone will have many new and profound effects, when long distance telephoning becomes more widespread, upon the distribution of population between metropolis and smaller city, upon the physical separation of management control from production, upon remote controls in general. The telephone wire may be used to record messages, bulletins, even newspapers in the home and office. Nor are the influences of the very common automobile matters of past history either. The new social and economic unit of population called the metropolitan area so encouraged by the automobile is in its infancy, while the trailer may be destined to change the habits of living and working of vast numbers of the people.

The problem is thus posed. The various papers which follow are attempts to answer this question in the light of present knowledge. But prior to their presentation the problem needs to be further amplified. This is done under the accompanying headings.

The Probability of Invention in the Future

That invention will continue in the future may be taken for granted. Still, it is desirable to support this assumption with some evidence. Such evidence is the record of patents in the United States. The number of thousands of patents issued every 10 years since 1880 are the following: 218, 235, 334, 401, and 442 in the decade 1921–30. It would be most unusual if such a continuous series of inventions should suddenly cease. In the first third of the twentieth century there were 1,330,000 patents issued in the United States. In the second third of the century even more than one and a third million patents may be expected, since the line showing the number of patents per decade is a rising one. But even if the curve should turn down-

ward, there would still be a very large number of inventions made.

The statistics are sufficiently convincing, but the message they bring is not often remembered, possibly because curiosity concerns particular inventions, not aggregates. The importance of the inventions previously discussed is not that they were six in number, but that they were the telephone, automobile, radio, rayon, motion picture, and airplane. Similarly, it may be argued that though there may be in the next 30 years more than 1,300,000 patents, there is no assurance that out of so large a number of inventions, there will be any of the rank or importance of the radio and the other five that were discussed. The point is discussed much more fully in the papers which follow. It is only necessary to note here that patents are of very unequal value; that while most of them are minor and at the base of the pyramid there are others of great importance at the peak. So, out of a million or more inventions, it seems reasonable to assume that some will be very important.

It should be observed that not all of these six inventions were made in the twentieth century. The patent on the telephone was granted to Bell in 1876. As regards the airplane, though the Wright brothers secured a patent in 1906, flights had been made here and abroad earlier and the heavier-than-air flying machine was recognizably under advanced development in the latter half of the nineteenth century. Automobiles were in use in the last quarter of the nineteenth century; and though the motion picture was made practicable in the 1890's the date of its invention has been pushed still further back. Hence, many new inventions that will aid in shaping our destiny in the next 30 years are in embryonic existence now.

Invention is a process, the granting of a patent being only an incident in the process. The idea of the invention is first conceived with some definiteness. It may then be demonstrated as a plan on paper or in the form of a model. Many years may be required before it takes concrete form. Then follows a period in which the design is constructed in a form that is workable. Improvements are then made and sales promotion efforts applied. If these two developments are successful, a point is finally reached where the invention is marketable. Only some time later does it become sufficiently sturdy, simple, and low priced that a relatively large sale is possible. The process is generally to be measured in decades and sometimes in centuries.

Since this report deals with the social implications of inventions, and since these implications manifest themselves where there is extended use of these inventions, it is possible to have considerable knowledge of these implications before the inventions attain large commercial success. Many of the inventions that will have marked social influence in the next generation are well along in the process by this time. So that the problem of finding out what will be the inventions that will have the widest and most significant social influence in the near future is not a problem of predicting inventions as much as it is of selecting inventions which will prove to be effective among those that are already known. While it is possible to do something toward the actual prediction of invention, as is shown in a later chapter, that is a different task from choosing among existing inventions those that will have great influence.

What Inventions Will Be Great

Since invention is not so much an act as a process, there is a lapse of time before the invention is perfected sufficiently to have extensive use. This period of time focuses then the search for existing inventions significant for the future. But even though this task may be less difficult than predicting inventions, it is sufficiently difficult to discourage anyone, not urged on by an appreciation of the great value to society of success, or not under pressure to do so by organizations that must plan and act in anticipation of the future.

The problem is difficult because the death rate of inventions is so high. The death rate has never been calculated, but it is much greater than the death rate ever was for human babies. For invention is in process from the fertilization of the idea on through various successive stages of development. On the other hand, perhaps, other reasons for anticipating a premature death of an invention are more discernible than in the case of a human infant. Naturally the nearer the end of its evolution the easier it is to pick the successful inventions.

For instance, 25 years ago a good deal was heard about the telegraphone, an invention that recorded a conversation or music on a magnetized wire, which could be used over again after demagnetizing. This invention would probably have been chosen at that time as a prospective successful invention of considerable social influence. Yet today nothing is heard of it. A quarter of a century ago these machines were put into commercial use. Indeed, stock in the corporation was sold generally to the public. As to why it is not in general use today many reasons are given; technical defects, suppression of the invention by others, the success of the phonograph, etc. Of course, the invention may not be dead. It may be revived.

The teletypesetter was announced about a decade ago, making it possible for one person sitting at one machine to set up the type for an indefinite number of newspapers, thus forecasting technological unemploy-

ment among typesetters. Indeed, the type of whole newspapers were actually set up by the teletypesetter, but the invention has not come into general use as yet. If it becomes widely used, as is expected, the lesson is that delays are often longer than anticipated at the time of announcement. The making of sugar from sawdust was known in 1927, but there is no news of its use. Newspapers were printed in Iowa on paper made from cornstalks several years ago, but no paper is made from cornstalks now, so far as could be learned from inquiry. Some years ago it was announced that clocks and watches could be kept accurate by radio waves. There have been thousands of similar announcements of inventions and discoveries which have not been used enough to leave any significant social influence.

Of many such discoveries announced, but not used, it may be incorrect to refer to them as dead. They may at some future time be brought into use. But when the purpose is to pick inventions that will be used in the next 20 or 30 years, then if they lie dormant during this period, the effect is the same as if they were dead.

So, also, if an invention is being selected that will be exploited from 1936 to 1950 or 1960, errors may occur because of the length of time required for perfecting an invention, a length of time often much greater than is anticipated. Thus cotton-picking machines have been announced at various times during the past two generations. Indeed, it is a fact that 900 patents have been granted on cotton-picking machines by the United States Patent Office. Also many reports in the past have been made that synthetic rubber was "just around the corner"; only recently are types of synthetic rubber appearing on the market. Several years ago discoveries for the cure of cancer were reported at the rate of one a week, but the death rate from cancer is about the same today as it was 20 years ago. The tractor was in use many years before it was made fully practicable for use on farms. In the case of television, it seems to be a case of the watched pot never boiling. Television and the cotton picker seem about to come through as do some of the others mentioned; but it takes a longer time than is expected. The making of wool from cellulose and of gasoline from coal are likewise slow in their development. So, with the uncertainties of the inventive process indicated by these illustrations it is quite difficult to say what inventions will be put successfully into commercial use in any given period of time, to a sufficient degree that they will have extensive influence on society.

If it is asked why inventions die early and what obstacles delay their use, a variety of answers may be made. One very great cause lies in technical faults. If an electric organ is built on the principle of photographing sounds on glass, it is readily seen that there are innumerable possibilities of imperfections. A chain is no stronger than its weakest link. Some years ago a multiplying machine was sold that would multiply two large figures with only one pressure on a key recording multiplicand, multiplier, and product on paper, but the machine got out of order so frequently that it had to be given up. Other inventions are unsuccessful because their promoters do not solve problems of repair service. Some inventions are so complex that special training is required to use them. New consumers' goods have a wider sale if they are simple to operate. Other inventions yield only some of the properties desired, but not all. Such is the case with many of the existing synthetic products used for rubber.

Obstacles of another nature to the adoption of inventions are the ready availability of substitutes which render very nearly the same service. Thus, paper may be made from wood pulp as truly as from cornstalks. A very large number of inventions are held back for this reason.

A difficulty of a different order is the cost of production, which must be relatively low for the invention to find a market. Such is the difficulty at the present time with gasoline made from hydrogenated coal.

A different class of difficulties lies in the economic sphere. The business enterprise and ability required to manufacture and market an invention are not always quickly available. Monopolies do not adopt inventions as readily as do competitive industries. Existing capital equipment that would be scrapped if the invention were used is another obstacle. Vested interests that will lose because of a new invention are lined up against its use. A State may hold back an invention for social reasons, for example, because it may bring unemployment. Popular opinion may not favor the new invention, as in the case of the introduction of a new calendar.

It is clear from the discussion, then, that the task of choosing the important inventions that will be used enough to have influence on society is a hazardous one, even though the particular inventions to choose from be in existence at some stage of their development. In closing this phase of the discussion, it may be remarked that there is no fully satisfactory reporting of scientific discovery and invention, hence an expert is required for even a small segment of the field. However, the contributors to this report have been requested to try their hand at attempting to indicate the technological trends in certain rather large areas of advance. The importance of such attempts lies in the great significance of technology for government, industry, and the other social organizations, which is the next subject to be discussed.

Technology and National Welfare

The United States is greater today than were the Indian tribes that lived here before the sixteenth century, in part, at least, because of a superior technology. With the Indians it was relatively crude. The difference was not due to natural resources, for they were the same for both peoples. England's prestige and power during the nineteenth century rested in part upon her early acquisition of the machines and transportation agencies over the neighboring powers who still used the handicrafts. Germany has been in the vanguard in industrial chemistry, which has greatly added to her power.

But this investigation is not concerned with technology as such nor national power in general, but rather with the influences of specific technological developments, as may affect various national interests. Thus poison gas is a scientific discovery that places a powerful weapon of attack in the possession of an enemy, and affects the balance of powers among nations giving advantage to bold offensive states. Similarly, in an earlier age, the use of gunpowder was a powerful factor in breaking down the system of life built around the feudal lord and his castle. It is well known that the use of steam in connection with machinery made of hard metals has greatly changed family life, taking industrial production from the home and somewhat later a proportion of married women too, eventually aiding the extension of suffrage and encouraging the entrance of women into political life. The automobile has changed the problem of the apprehension of the criminal and was a factor in the assumption of new police responsibilities by the Federal Government. Sometimes relatively simple technological developments may raise profound problems. Thus discoveries in regard to methods of birth control are affecting the relative strength of military establishments of different nations, and are objects for suppression by the most aggressively warlike powers. On the other hand, the differential diffusion of these methods leads to a contribution of one-half the population of the next generation by one-quarter of the present generation, and that one-quarter is made up disproportionately of those with low income.

It is clearly seen then that scientific discoveries in applied science and invention do have important social consequences that greatly affect public policies. The subject is then important, not because there may be isolated cases of influential technologies as might be inferred from the few illustrations cited, but because the technological equipment is of such great magnitude, a fact which calls for a brief discussion.

The Volume of Technological Change

Our times have been called the machine age, because of the almost inconceivable variety and number of inventions and discoveries affecting every field of human endeavor. Not all those inventions are of the order of the airplane nor do they all have the far-reaching effects of the automobile. But there are several that do: with many more less significant ones exerting smaller social influences. To conceive of the role of technology one must think of the influence of any one invention, or of a manageable number multiplied many thousands of times.

The magnitudes are difficult to appreciate; but it is commonly said that a greater part of all social changes of modern times are precipitated by technological changes. Indeed it is not easy to think of a single social problem whose present nature is not influenced in part by one or more inventions of recent times.

For instance, the problem of social security can readily be related to a number of inventions without undertaking any extensive analysis. The large proportion of elders insecure in their old age is affected by various inventions, such as those making possible a smaller proportion of children, by urban factories and agricultural machinery which increased the population of cities, by transportation inventions which move sons and daughters to various parts of the United States and even to other lands, and by machines the tending of which employers prefer young persons to old ones. Thus new inventions bring insecurity to the aged. There is also the problem of security of employment. The large numbers of unemployed are in part due to machines taking jobs away and in part to business depressions which do not last long in civilizations not based on machines. The insecurity of the sick is occasioned in part by the high cost of medical service resulting from the development of science in medicine which gives rise to expensive specialists and to a technological medical equipment which means a large capital outlay for the physician, necessitating a charge of high prices to pay interest on the investment. The modern problem of workmen's compensation is directly traceable to whirling steel.

Even problems that are common to all societies and hence are not caused by changing technologies, as war, crime, divorce, disease, take on new forms or new degrees of expression under the impact of changes precipitated by technology.

The environment of modern men is to a surprising degree made up of machines, much as the environment of wild animals is made up of fauna, flora, wind, rain, and temperature. Even those men and women who do not work on a machine for a living are only once removed from it or its products. Modern man's prob-

lem of adaptation to his machine-made environment is different from the problem of primitive man in adapting to nature because the machine-made environment is rapidly changing, and this is not the case with nature.

How Scientific Achievements Produce Social Changes

An invention usually affects first the persons using it directly. If it be a producer's goods such as a farm tractor, it means at once the replacement of horses or mules, the purchasing of gasoline, and changes in various other farm practices. If it be a consumer's goods such as an air conditioning unit in a home, it affects the construction and use of the house, but of course the units must be fabricated and hence, for that purpose, factories must be created, marketing machinery set up, etc. All such results are called the primary influences of the new technology.

These primary effects may flow out in different directions. Thus the X-ray is used for purposes of diagnosis in medicine and in dentistry. At the same time it is used in therapy as in the treatment of endocrine glands. It is also used in industry to detect minute flaws in the interior of steel castings or other solid objects. Indeed, manufacturers of the X-ray apparatus have noted some sixty different uses of the X-ray.

Similarly there are many different influences of radio. Some 150 were reported in the study of inventions in Recent Social Trends. Radio waves are used in guiding ships to port, as danger signals when a navigator is in distress, in flying airplanes, in program broadcasting, in point-to-point telephoning, in medicine, and in exterminating parasites.

These primary effects are not all exerted at once. Just as it sometimes requires 30 or 40 inventors working over a long number of years to evolve a complex major invention, and just as it may require hundreds of thousands of improvements spread out over time after the invention has been produced; so it requires a long time for the various uses of an invention to be determined. The phonograph was early used for recording dictation. Only later did it evolve into a musical instrument. Indeed, Edison, the inventor, did not think much of the possibility for the phonograph as a musical instrument, but thought it might have some use as a toy, and for recording the last words of dying persons. One does not yet know what may be the possible uses of the cathode ray.

Each of these primary effects may, in turn, produce derivative effects. Thus, as the tractor replaces animals on the farms there follows as a derivative influence less need for horse feed, which means that the land used for growing such feed is turned to other uses. This is a secondary effect. As land formerly used for stock feed yields other crops, the quantity is increased of other agricultural products, which tends to lower their prices. These lower prices are, in turn, mirrored in land values, perhaps in demands for tariff protection. Thus, these various derivative influences occasion effects secondary, tertiary, and so on. Each effect follows the other much like links in a chain, except that the succeeding derivative effects become smaller and smaller in influence. The effect of the tractor on lobbying for a higher tariff is very slight in comparison with other forces. A derivative effect in another direction is the stimulation the tractor brings to the cooperative movement in various ways, but especially in the purchase of gasoline.

In general, the first primary effect of an invention is found in (a) the economic practices of production and (b) in the habits of the consumers using the finished product. The economic organization as a whole may be the secondary influence if the technologies concerned are important ones. Thus, the tractor has the influence of making farms larger because on the smaller farms a tractor will not pay. Time is required to purchase additional land and to consolidate farms. In other ways tractors influence the agricultural economic organization. They make the adjustment to a business depression more difficult than in the case of horses and mules, for in a depression it is easier to raise feed than to buy gasoline. The tractor also moves the farmer a bit closer toward specialized commercial farming as contrasted to subsistence farming. Very many of the great inventions following the so-called Industrial Revolution have been machines affecting industrial and economic life, namely, gasoline engines, motors, steamboats, chemical and metallurgical inventions. Very often, then, the first great social institution affected by these changes has been the economic organization.

Later derivative effects impinge on other social institutions, such as family, government, church. Thus, the great economic changes that followed the power inventions modified the organization of the family. Women went to work outside the home. Children were employed in factories. The home gradually lost its economic functions. The father ceased to be much of an employer or manager of household labor, at least in cities and towns. There followed a shift of authority from father and home to industry and State. In cities homes became quite limited as to space. More time was spent outside by the members of the family. In general, then, these changes in industry reacted on the family life.

In a similar way inventions have impinged upon government. In some industries the nature of invention was to encourage monopolistic corporations deal-

ing in services used by a large number of individuals or other corporations. Hence governments took on regulatory functions as in the case of the public utilities. Taxation measures shifted from general property, tariffs, and excises on consumption goods to taxes on personal and corporate incomes and on inheritances. In many other ways the government was forced to extend its functions, as in the case of interstate commerce. City governments, especially, had to assume many more activities than those exercised by counties, where wealth was produced largely on farms without the use of power machines.

Thus, the great inventions which first changed industry produced derivative effects on other social institutions, such as government and the family. Finally these, in turn, have produced still another derivative effect upon social views and political philosophies. The attitude toward the philosophy of laissez faire eventually undergoes change as more and more governmental services are demanded, despite professions of the old faith to the contrary. The philosophy regarding home changes too. It is not so clear under the new conditions of the machine age that woman's place is in the home or that the authority of paternalism in the family is exercised as wisely as it was thought to be in the days of our forefathers. Also attitudes toward recreation and leisure time change, with city conditions and repetitive labor in factories. That these attitudes are so slow to change and are often near the last of the derivative effects of invention may appear surprising. It is true that these new attitudes always appear quite early with some few advanced individuals, leaders, and martyrs. The social philosophies of the mass of citizens do not change so early. Observation seems to indicate that the ideational philosophies hang on, become subjects of reverence, and are in general the last to change in any large way.

In concluding the observations of the way technologies exercise influence, an invention may be likened to a billiard ball, which strikes another ball, which in turn still another, and so on until the force is spent. Changes are started on one institution which impinge on others, and those on still others. There is great variety in these sequences; but in the past in many important cases the change occurred first in the technology, which changed the economic institutions, which in turn changed the social and governmental organizations, which finally changed the social beliefs and philosophies. This conclusion does not preclude, of course, the importance and prevalence of other social forces originating from sources other than invention and following this or other sequences. These are not, however, the subject of this report which deals with technology.

Those, then, who would anticipate the social consequences of technologic changes must recognize the process of derivative influences. The preceding description of this process, it may be noted, applies to groups of inventions as well as to particular invention. The reason of this is that often a multitude of inventions all lead toward the same general social effect. This phenomenon must next be discussed.

The Same Social End From Many Different Inventions

The importance of this observation that different inventions lead to much the same social result lies in the fact that because of it the prediction of social consequences of inventions is aided. It may be indeed less difficult for this reason than the prediction of technological changes. The growth of the suburbs might have been forecast for the reason that they are encouraged by a number of recent inventions, not just one. Some of these are the steam railroad, the electric railway, the automobile, the truck, the telephone, the chain store, the radio, and the motion picture.

Another case is the influence of inventions on privacy and isolation, that is, the transmission of communications into the home community or place of work. Mail delivery was early in bringing changes. Then came the telephone, which was quite an intrusion. Lately there is the radio. There are now further possibilities, an instrument that will record a message delivered by telephone whether the ring is answered orally or not. The teletype is still another device for bringing messages, which is found now in different offices. If facsimile transmission does not print newspapers in the home, or at least leave bulletins of news, stock market quotations, or weather reports they may be had by radio broadcast. The phonograph brought music into the home before the radio. In addition television will further bring intrusions and break down isolation. One may then foresee the individual as being more and more subject to the influences of propaganda or education. The power of mass appeals will be greatly strengthened because of these inventions all pointing in varying degrees to the same end.

This principle spoken of as that of substitute inventions is discussed more fully in a later chapter, in regard not only to forecasting social effects of inventions but also inventions themselves. Why is it that the influences of different inventions are grouped in clusters? It would seem as though demand is the answer, commonly implied in the old saying that necessity is the mother of invention. Such a proverb is only a part truth, for there are many cases to show that necessity did not produce the invention needed. But there are also plenty of illustrations that social demands influence the direction of invention.

A very good illustration is one discussed in another chapter, that of securing useful information about an individual. In a stable community with aggregations of population little larger than a village an individual becomes generally quite well known even to his minute idiosyncrasies. The requirements of the tasks which he or she is sought to perform are also generally known. The situation is quite different in a complex society undergoing rapid change with large populations and a good deal of mobility. There is thus an urgent demand to know more about individuals. So there are psychological tests, school grades, fingerprints, lie detectors, case history records, vocational guidance agencies, etc. The influences of these various inventions all flow into the same groove leading toward more information about the person concerned. It is the social need that determines the groove. From this point of view it would appear that social influence creates invention as truly as inventions have social influences. Such is the case. Social valuations do help to produce inventions but it must be recognized that there are limits to the power of necessity to bring forth invention. The discovery of effective cures for insanity has yet to come despite the long-standing need. On the other hand an invention will not be used if there is no need or if a desire for it cannot be stimulated. There must be some receptivity for a discovery before its influence can be felt, particularly the primary influence. The derivative influences are not however the result of the need of the invention itself and sometimes occur not only when they are not needed but when they are harmful, as in the case of automobile accidents. Workmen's compensation is a derivative influence of the use of dangerous machinery but such an insurance was not the necessity which helped to encourage the use of fast moving machines.

If then a survey of a number of inventions points toward one social end, there is more assurance in looking forward toward such a result as a probability. This conclusion is not however the basis of organization of this report to the National Resources Committee. That is to say, the contributors who are specialists in technology and science do not choose such topics as satellite cities, vocational guidance, isolation, marketing, the home, and try to trace out the inventions whose influences are flowing in on them to see whether there is an accumulation or not. A program of research of this nature would be, though, a very desirable one to undertake with the proper time and support. The basis of organization of this report is rather to canvass the new inventions in the different fields of technological advance as a basis for tracing outward the influences that flow from them. The first step in such a plan is to secure experts in the different fields to report on the probable technological developments in these fields. These reports can then be the basis for attempts to ascertain the social implications.

The Time Lag Between Innovation and Social Effect

Some time elapses before the full effects of an invention are worked out. This time element furnishes an opportunity of studying and forecasting what the social consequences may be.

Some of the effects take place after only a very short delay. The talking pictures threw the orchestras of the moving picture theaters out of work quicky. Similarly the tractor when it had been made suitable to the farm brought unemployment to horses quickly. The automobile affected the carriage manufactures soon. In these cases the effect on a single unit is almost instantaneous. The woman who uses an electric washing machine does not use the old hand washtub. But one case does not make a social situation. Many tractors must be used before the transfer of lands from horse feed to other uses will affect the prices of agricultural products. The displacement of one orchestra by the talking picture adds only a few to the unemployed but after a time ten thousand or more may be thrown out of work. The social significance of an invention depends on the frequency of its use. One automobile will not congest a city street, but a sufficient number will necessitate traffic police and signal lights.

It is not only the frequency of a single type of use of an invention that indicates its social significance, but also the variety of its uses. Thus the automobile forced city governments to abandon the old fire horses. But there was a delay. The city governments did not always make the change as soon as the opportunity was presented. In these cases it is not unreasonable to expect that it could have been foreseen that fire engines would be driven by combustion engines rather than by horses. So also one might have foreseen the greater use of traffic police because of the automobiles, though such a prediction would necessarily have to be based on a consideration, among other things, of the future price of motorcars, which would present difficulties.

The derivative effects of inventions are more difficult to anticipate than the primary effects, but there is also more time for studying them, for the derivative effects are delayed longer. The effect of the tractor on agricultural prices because of the shift in uses of the land takes some time, partly because of the influence in volume of use, but also because agricultural price is a derivative influence.

These derivative influences are delayed because there are usually a number of other determining factors

affecting them than the one of invention alone. Thus agricultural prices are affected often in a world market by many other factors such as climate, business cycles, volume of credit, and so forth. These other factors tend to minimize the magnitude of these derivative influences of an invention and also to slow them up. The cotton gin increased the production of cotton, and this greater yield might have been foreseen. The derivative influence of increasing the number of slaves is less easily seen, for the number of slaves depends upon their availability through purchase from other lands, for which capital was required, or from natural increase, which took time. That the Civil War could have been foreseen as a derivative influence of the cotton gin is extremely doubtful, for there were too many factors other than the cotton gin causing the war, many of which were subject to human control.

Derivative influences of inventions do not seem necessarily to be inevitable, as the term is generally used. Such, theoretically, was the case of the Civil War. There was an element of choice or will power. Another illustration. Modern industrialism and the inventions leading to the growth of intangible property have rendered inadequate the general property tax, still common, however, as a source of State revenue. These inventions should have made this tax obsolete, but it is a derivative effect far removed. Human action, based on will, is needed to change the general property tax. The delay in this case is measured in terms of centuries.

Delays of this nature are sometimes occasioned by the difficulty of making a collective choice. Concerted action requires more time than that of a single individual and meets with more obstacles. Thus modern transportation, together with some other recent inventions, has rendered the size of counties less suitable as an administrative unit in many areas, especially where the counties are small. In some States a citizen can ride in an automobile on a paved highway from his home to the State capital in as short a time as he could drive in a horse and buggy over the bad roads from his farm to the county seat when the county system was founded. Many county governments cannot provide the necessary social services. Yet delays occur in either widening their boundaries or providing other adequate machinery. These delays are due in part to the difficulty of collective action, particularly as the local politicians have great influence with the voters. There are, no doubt, other influences, such as local pride in being a county seat. But whatever the factors, this adjustment of local administrative units to proper boundaries is not made because of the difficulty of collective action.

These lags in the derivative effects of technologies then precipitate the issue of values, whether one effect is desirable or not. In the case of the general property tax and of the county government there is general agreement that the delay is undesirable but in other cases there is no such unanimity of agreement Such is the illustration of closer contacts with Europe brought about by the transportation and communication inventions. Some observers would make the choice of further isolation for the United States while others would propose one or more of various types of closer relationship. In the case of these derivative effects of invention, delays are long, collective choices are difficult, and the issue of policy is raised.

While the delay between the origin of an invention and its various social consequences may be quite long and thus allow time for the anticipation of these social consequences, planned action may not necessarily follow even a successful anticipation, for planning means choice and a decision to act on the plans. Thus it becomes desirable to extend the discussion of technology with its delayed social effects into considerations of planning.

Policy, Planning, and Technology

One important lag in connection with the policy of society toward invention lies in the rate of adoption of new invention in the place of existing machinery. A conspicuous trait of the dynamic age in which we live is to be seen in the rapid pace at which existing capital equipment is made obsolete by technical inventions and other innovations in the design and construction of consumption and capital goods. Economists and business men have always been aware of the effects of this rapid rate of change in bringing capital obsolescence. But special attention has been focused on the obsolescence of capital equipment by the industries making new equipment. Trade journals and industry associations have stimulated study and collected data on the extent of obsolescence. In 1934, the trade journal Power made a study of 454 "better-than-average" industrial power plants constituting nearly 10 percent of industrial primemover capacity and found 62 percent of the equipment was over 10 years old while 25 percent was over 20 years. Some of the older equipment was presumably used as standby plant for emergencies, but the bulk of the older equipment was regarded as obsolete to such an extent that, by replacing it by facilities of the most advanced design, 50 cents could be saved, on the average, out of each dollar spent in the older plants for industrial power. In 1935 the American Machinist made a study of the obsolescence of metal-working equipment, concluding that, because of the rapid improvement in machine design, metal working equipment was as a rule obsolete

if not produced within the last 10 years. It took an inventory of the age of such machinery and found that 65 percent of all the metal-working equipment in the country was over 10 years old and presumably obsolete. The Interstate Commerce Commission records indicate that 61 percent of the steam locomotives in the country were built over 20 years ago. These figures suggest the magnitude of capital obsolescence.

Further light on the magnitude of capital obsolescence is thrown by the estimates of the potential machinery requirements of all industry made in 1935 by the Machinery and Allied Products Institute. This institute made an extensive survey, sampling the requirements of industries covering over 85 percent of all industry, and on the basis of this survey estimated that the potential machinery requirements of all industry amounted to over 18 million dollars worth. Of this amount over 10 billion consisted of new equipment to replace old equipment which was for the most part obsolete.

Obsolescence surveys like the ones above referred to clearly indicate the magnitude of capital obsolescence. Yet the social implications of capital obsolescence have received very little study and a whole series of questions are waiting to be answered. When equipment becomes obsolete and therefore loses value who suffers a loss? Does obsolescence involve a social cost or only a business cost? Is capital obsolescence a cause of industrial maladjustment? Does the existence of extensive obsolete equipment prevent the using of better industrial techniques? Can the risks of capital obsolescence be reduced without impeding the use of better techniques? Should the losses due to capital obsolescence be distributed throughout industry? So little is known of the actual impact of capital obsolescence on industrial activity that no answer can be given to these questions. Yet they are questions forced on us by our rapidly improving technology and deserve the most careful study. Capital obsolescence and all that it involves needs to be extensively studied if the full social implication of current trends of improving technology are to be appreciated and the problems presented by improving technology are to be met.

But after inventions are adopted, the social effects do not come immediately as has been shown in the preceding section. There would thus seem to be time to consider the social implications of inventions. The difficulties in planning lie in other directions.

One of these difficulties is the unwillingness to admit the great role which so material a thing as technology plays in causing problems in society. It is only recently that one would admit that a man was unemployed because a machine had destroyed his job. The explanation, all but universal, was that a man was out of work because he wouldn't work. The forces of society were wholly moral. The driving forces that changed things were great ideas. With the requisite great men and the proper leadership, all problems could be solved. Solutions were seen in terms of moral conduct, the proper choices and the necessary will power. That a nation could not be a great power without coal and iron was not readily admitted for it posited a materialistic limitation. But with machines all about us during our daily life in this the great machine age, their great influence cannot be gainsaid. Such an awareness of material things makes no denial of the power of ideas, of ethics, of will power, of great leaders. But it does insist on the necessity of taking into consideration in planning the great influence of machines and scientific discoveries. The planned use or distribution of natural resources of any nation are of little value without knowledge of what uses technologies will make of them. Will oil be made from coal? Will plastics take the place of wood? Will alcohol be used as a motor fuel? Will more food stuffs be produced chemically? These questions suggest the importance of a knowledge of scientific development in any planning in regard to natural resources.

Social institutions as well as natural resources are affected by technology as has been shown. The home was changed because a steam engine and the machines it drove were too large for a dwelling. Now there has come a new source of power readily available for home use, electricity. Will it restore to family life something of its former glory before steam reduced its functions? Another illustration is war, a function of all states in the past. It is affected by the discoveries of poison gases as a weapon of military offense particularly their distribution among civilian populations by airplanes. Such technological developments must be considered by governments for they affect the very life and death of states.

Granting that sound plans must be based on technological knowledge, and granting that technological development is sufficiently slow to permit time for study and planning, the task still remains very difficult. Also the task of forecasting a trend within a limited period, say the next 20 years, is a more difficult assignment than to have an unlimited time. And since plans are expected to be carried out in a definite time, what is needed is not to say that something will occur in the future, but within a definite time limit.

The difficulties in forecasting the social influences of mechanical inventions and scientific discoveries and the status of the effort at this time should not be considered as obstacles so great as to make the method useless for the very practical task of governmental planning. Indeed, the experience gained from this first attempt at describing the technological trends of the near future is such as to give confidence that

further efforts will be more fruitful and that much information increasingly reliable can be made available for governmental executives and legislators.

What, of course, is needed is a group of thinkers who will make it their business to devote a continuing study of some duration to future trends, and whose work will be given adequate recognition. The movement to study future trends would be furthered by the aid of new scientific journals devoted to this field or else by the granting of adequate space in the existing scientific publication media for studies of forecasting of both technological and social trends. In the world of social change of today, such a division of labor and specialization is altogether reasonable. Indeed it is more, it is essential for adequate attack upon the problems ushered in by social change. A decade of organized effort devoted to such inquiries into future trends would result in contributions of the utmost value to the formation of governmental policies and plans.

How the governments will act on the basis of such contributions is another question. For presenting conclusions is different from acting on the basis of those conclusions. Plans of action involve policies which are based often on values and choices. Governments are very often at the crossroads of important decisions. Government is not a passive agent molded by the forces evolving from technology.

For these reasons the effect of invention on the State is often longer delayed than is the case with other social organizations. For instance, it is obvious that modern transportation carries its freight and passengers across State boundary lines much more frequently than in the early history of the Nation. Los Angeles is now as close to New York as Philadelphia was at the time the Supreme Court was founded. Industry transcends State lines and the market for most economic goods is Nation-wide. Though these things be true, yet the people and the Government are not decided as to just what policy to follow in regard to the reduction of distances by the transportation inventions. There are some who would try to keep business small and within bounds manageable by the 48 different States. But there are others who feel the need of one strong centralized government to deal with industries, so many of which it is claimed are extending in influence beyond the boundaries of any one State. This illustration shows that though the growth of transportation is well recognized and that its effect on State boundary lines and local government may be seen, yet decisive action on the part of Government may be delayed.

In other words, even though changing technology may give information about future social conditions which may be used as the basis of planning, such knowledge may not be acted upon. For successful planning rests upon other factors than knowledge, particularly unanimity of purpose, the will to act. The place which a knowledge of technological trends occupies in planning is only to furnish information without which plans are likely to be uncertain. Even though unanimity of purpose exists and the will to act is present, without knowledge as to what is likely to happen in the future, such plans as may be made will be to that extent defective.

At the beginning of the twentieth century it was shown that the Nation stood on the threshold of a great development of important inventions, such as the telephone, the airplane, the radio, the motion picture, the automobile, and the manufacture of artificial fibers which were to affect profoundly all phases of national life. The Nation faces now the second third of the twentieth century. What may be expected in technological development?

How far reaching will be the effects of the mechanical cotton picker? Will the surplus labor of the South flood the northern and western cities? Will the governments plan and act in time, once the spread of this invention is certain? The influence on Negroes may be catastrophic. Farm tenancy will be affected. The political system of the southern States may be greatly altered.

In another field, science has gone far on the road to producing artificial climate in all its aspects, which may have effects on the distribution of population, upon health, upon production, and upon the transformation of the night into day.

Then again television may become widely distributed, placing theaters into millions of homes and increasing even more the already astounding possibilities of propaganda to be imposed on a none too critical human race.

Talking books may come as a boon to the blind, but with revoluntionary effects upon libraries and which, together with the talking picture and television, may affect radically schools and the educational process.

The variety of alloys gives to metals amazing adaptabilities to the purposes of man.

The use of chemistry in the production of new objects in contrast to the use of mechanical fabrication on the basis of power continues to develop with remarkable rapidity, in the production of oil, of woolen-like fibers, of substitutes for wood, and of agencies of destruction.

So the immediate future will see the application of new scientific discoveries that will bring not only enticing prospects but uncertainties and difficulties as well. This report is offered as a first study of the basis of the impending changes which shape the Nation's course in the future.

II. THE PREDICTION OF INVENTIONS

By S. C. Gilfillan [1]

In dealing with the predictability of inventions a first step obviously is to turn to past experiences, where considerable time has elapsed between the predictions and their success or failure as shown by actual events. A long list of inventions which had been foretold aright could be drawn up easily. But particular predictions from anyone's pen might be right through sheer accident, whereas other predictions by the same writer might be mostly wrong.

Can Inventions Be Foreseen?

A surer proof of the fact that prediction may be carried on with a high average of success can be found by considering all the predictions within a given category, perhaps all those in a single book, or in articles by certain writers. A great number of books and articles can be found whose forecasts have been highly mistaken. Some of their authors, like Jules Verne, were not seriously trying to predict the nearer future; others may have been using wrong methods. Careful examination of the work of writers who have repeatedly predicted inventions with a high percentage of success, may lead to successful imitation or even improvement of their methods.

In the Scientific American of October 1920, there appeared a long editorial article, The Future as Suggested by the Developments of the Past 75 Years, by A. C. Lescarboura and others.[2] It was aimed not more than 75 years in the future, and commonly less, and reads today as a very reasonable, clear-sighted preview of the developments of the past 16 years, and of those that we would still predict today. It is hard to measure the degree of correctness, from the difficulties of counting prophecies, evaluating those whose possible fulfillment is still in the future, and taking account of conditional and hesitant predictions. Still we may say that, of the 65 definite predictions of invention in this article, 38 percent have been already verified; 20 percent are nearly certain to be verified, according to the writer's opinion today; 8 percent have been proved wrong; 3 percent will be proved wrong, in the writer's opinion; and 22 percent are doubtful. Separating the doubtful equally between right and wrong, and adding the classes, the writer would say that probably 78 percent of these definite predictions have been or will be verified, and 22 percent found wrong. The proportion right is much larger than one would expect from mere luck, without any power of foreknowledge. But we do not know how to estimate [3] the number of hits that could have been obtained by sheer luck.

Some limitation of the alternatives facing the forecaster appears in the cases where he chose only to say that the trend would be in a certain direction, as toward more canals, or progress in overcoming static. There were 14 technical predictions of this sort, not counted above, in the article, and all were right.

There were no gross blunders in this article, and no evidence of lack of technological competence. But there were two striking failures to foresee—first, radio-telephonic broadcasting, whose beginning is usually taken as KDKA's, just one month later, in November 1920. Radiotelephony is not even mentioned in the article, although an old art, and one cited elsewhere in the same issue. We shall note later how its broadcast possibilities were overlooked by almost everyone. The article under study gave 6 percent of its space to radiotelegraphy and phototelegraphy, and correctly predicted broadcasting—"subscribing to concerts and motion pictures for the home, the service being distributed over the usual telephone lines by a central studio", thus managing to predict broadcasting due to the important principle of equivalent invention, to be discussed later.

The other most important invention introduced in the period covered, the talking picture, was likewise omitted, with the movies, from this article. Yet the talking picture had been realized since about 1887, and had been a favorite item for prophets since 1890. In the same issue of this 1920 journal a cautious writer on photographic inventions says that talking and color movies have been created and expected by some, but are hardly needed. Failure to foresee the uses and

[1] Formerly Curator of Social Sciences, Museum of Science and Industry, Chicago, Ill., and author of The Sociology of Invention.

[2] Sci. Am., v. 123, pp. 320–321; Oct. 2, 1920. By Austin C. Lescarboura with collaboration of J. B. Walker on civil engineering and J. M. Bird on science.

[3] It would be very helpful if we could estimate the number of possible forecasts, among which choice was made; for the greater the range of possibilities, the less is the chance of a hit by sheer luck. One might artificially restrict the number of chances by a questionnaire, asking various competent people to mark the status, say, of radio control 20 years hence, as either nothing, slight, considerable, or vast; then reexamining the questionnaires 10, 20, and 50 years hence, study statistically how nearly people were right, and what sort of predictions were correct and why. This would be an easy and excellent inquiry to start now, for future utility—the measurement of foresight. It might improve prediction as much as other arts have been bettered, once statistical and exact measurement was introduced. But with other arts the measurement was promptly useful, whereas with prediction we must wait for years to test our experimental data.

usefulness of known inventions has been a conspicuous shortcoming—and one which the present volume endeavors to correct.

Home talking pictures and transoceanic radio broadcasting both were foretold in another remarkably sound and prescient article, by the great electrician, Steinmetz, 21 years ago.[4] Looking ahead he saw housekeeping thoroughly electrified, automatic air conditioning, current so cheap that meters would not be installed, but flat rates charged, a law against lighting any fire in the smokeless city, the power plants all placed at coal mines, oil or gas wells or waterfalls. It is a utopian picture, yet seemingly well justified by developments to date. Of the 25 predictions, there can be figured 28 percent fulfilled, 48 percent destined, none wrong, and 24 percent doubtful. There is only one sheer blunder, and that was not prophecy, but an attempt at botany.

Somewhat similar were the optimistic views of Edison 4 years earlier, though still mostly to be tested by the future.[5] Hudson Maxim did well in 1908.[6]

George Sutherland's 20th Century Inventions, written in 1900, is mostly wasted through his attempt to tell just how things could be done in the future, his proposed inventions being uniformly bad. But where he speaks of the inventions of others he has been verified 50 percent of the time, according to a sample of 36 cases, and apparently will be in 10 percent more, in error a third of the time, and 2 cases doubtful, or say in all 64 percent right. He foresaw picture telegraphy, radiotelephony, wireless clocks, controls, and perhaps power, and an equivalent of the recording telephone. But as to aviation and the submarine he shuts his eyes to the light: "The amount of misguided ingenuity which has been expended on these two problems of submarine and aerial navigation during the nineteenth century will offer one of the most curious and interesting studies to the future historian of technologic progress."

A similar book, but less cursed by personal ingenuity and alive to others' inventions and their consequences, was written in 1906 by another English writer, T. Baron Russell, A Hundred Years Hence.[7] In a sample of 33 technologic predictions, 46 percent have been and 24 percent will apparently be verified, 21 percent seem erroneous, and 9 percent doubtful, or in all, 74 percent right.

Still earlier successful forecasters were Elsdale[8] and Crookes.[9] H. G. Wells has predicted much, but not often to our point, since his forecasts of inventions have usually been too remotely in the future, and his short-range predications are usually in the social realm, not about inventions. But he issued in 1902 an inspiring appeal for a science of prediction,[10] and his Anticipations that year is about as successful as his contemporaries' books, with numerous forecasts on the automobile age, housekeeping, and war.

The predictive capacity of the present writer may also be tested on the basis of five articles published as long as 25 years ago.[11] One on future, or utopian housekeeping, proposed no dates, and allowed for unlimited delay. "The centralized kitchen will come, not when (pneumatic) tubes are invented, but when women will see the merit in someone else's cooking, or the grocer, the teamster, the shopkeeper see the rightfulness in a change that would wither their occupations." The article remains as good, or poor, prophecy as ever, no great progress having been made toward the rational centralization and professionalization of the various housekeeping tasks. A 1913 article was on the growth of future liners, with a graph of their future lengths. Many have presented the like, but this article alone predicted a decline of length from 1,200 feet, beginning in 1935, just when two of the three last record-breaking leviathans we may ever see were being unwillingly completed. The progress of aircraft and of railroads to be built parallel to marine routes was given as the reason for the liner's decline, since if these removed the fastest and best-paying traffic, smaller and slower ships would be wanted. The aircraft prediction seems about to be verified; the railroad one has not been. A 1912 article on the Future Home Theater, quite correctly predicted the home talking picture and television set of today and tomorrow and their uses, although the writer was so ill-informed as quite to overlook radio, succeeding only as a result of the principle hereafter discussed

[4] You Will Think This a Dream, by Chas. P. Steinmetz; in Ladies Home Journal, Sept. 15, 1915, 32: 12

[5] The Wonderful New World Ahead of Us—some startling prophecies of the future as described by Edison and reported by Allan L. Benson; in Cosmopolitan, 1911, 50: 294 ff

The Inventions of the Future; interview with John R. McMahon; in Indep. 68: 15–18, 1910.

Today and Tomorrow; interview with John R. McMahon; in Indep. 77: 24–7, 1914.

[6] Hudson Maxim: Man's Machine-Made Millennium; in Cosmopolitan, 45: 569–76.

[7] A Hundred Years Hence—the expectations of an optimist. Edinburgh and Chicago, 1906.

[8] Lt. Col. Henry Elsdale: Scientific Problems of the Future; in Smithson. Instn. An. Rept. for 1894

[9] Sir William Crookes: Some Possibilities of Electricity; in Fortnightly Rev., February 1892.

[10] Discovery of the Future; in Smithson. An. Rept. for 1902, pp. 375–392.

[11] S. C. Gilfillan: Housekeeping in the Future; in Indep., 72: 1060–1062, 1912.

The Size of Future Liners; in Indep., 74: 541–543, 1913.

The Future Home Theater; in Indep., 73: 886–891, 1912

In a most obscure print, Gilfillans Gazet, New Years 1917, 30 prophecies still for the future.

In Scarlet and Black, of Grinnell College, Iowa, Feb. 2, 1925, a discussion of television, clear fused quartz, the rotorship, and mercury engine, as particularly promising inventions.

of equivalent invention. If a revised edition of each article were to be published today, there would be few words requiring change.

Prediction in Various Special Fields

Some brief examinations of the success of prediction generally in certain special fields—military, airplanes, radio, and television—should be instructive. These categories have not been covered fully enough for statistical analysis to be used. Rather, this review is intended to give a general idea of how prediction has gone, why it has been more successful in certain fields and by certain kinds of seers than by others, and how it might have been done much better, had the most capable predictors been fully awake to the latest developments and thought of their time and of one another.

In the forecasting of military inventions, what is striking is the usual poor success of those who published. H. G. Wells claims an exception for Bloch, a Polish banker who, in 1897, predicted that war must lead to a deadlock of trenches, and of economic exhaustion, such as did arrive for Central and Eastern Europe after 3 or 4 years' fighting.[12] His predictions in more detail were largely mistaken. Wells' revision of 1902 was a more successful study. It seems that the military arts are so progressive, and the value and possibility of invention so well recognized (despite claims that all revolutionary military inventions have been made by civilians), and the latest developments and projects are held so closely secret, that it is impossible for an outside author to outguess the silent inside experts, unless he ranges far into the future.

Thus, a humorous French article[13] of 1883 did succeed in predicting tanks, gas shells and masks, liquid fire, mine-laying by submarines, railway guns, the importance of artillery, dirigibles, airplanes, air torpedoes, anti-aircraft artillery and observation posts, and telephoning from an airplane by a trailing wire, which can be done if the airplane circles about. In short, this article foretold about all the novel implements of the war 35 years later.

The airplane has had no lack of forward-looking inventors since the first attempts in the Middle Ages, on through Ader[14] who flew 50 meters in 1890, and was then financed for 6 years by the French Army, down to the definite success of the Wrights in 1903. The guesses of the early aviation enthusiasts, e. g., Baden-Powell, as to types, dates of success, speeds to be attained, and uses for flying, seem to have been about right, while as much cannot be said for the professional predictors, in the decade when airplanes were just beginning to fly. Fair forecasts of the present of aviation and its uses were made by the specially informed Kaempffert in 1911.[15]

Wireless telegraphy, or at least the transmission of electric shocks through a body of water, or by conduction or induction, is nigh 2 centuries old, and was practiced for communication by Morse in 1842. Wireless telephony by electromagnetic waves was observed in 1884.[16] The familiar radio waves were suggested for communication by Elihu Thompson in 1889, the year after Hertz first detected them. Presently, Crookes proposed the same. About that time Sylvanus Thompson offered for £10,000 to establish communication by induction with South Africa. So there has been no lack of suggestions for the forecasters, long before wireless telegraphy burst on the world about 1900, and radiotelephony in 1922. Sutherland in 1900 proposed, as has been noted, radio control of clocks (an invention which various manufacturers are racing to realize today) and radiotelephony.

Telephony with Hertzian waves, our own radio, was first achieved by Fessenden in 1900, and on Christmas Eve of 1906 he broadcast music, and the next year speech clearly over 200 miles. DeForest at the same time broadcast Caruso singing, and the ethereal music of the telharmonium. But in an article wherein Fessenden discussed well the uses of point-to-point wireless telephony, he did not mention broadcasting. There were very few others who thought of it until the opening of KDKA on election night, 1920.[17] Dr. Frank Conrad had begun broadcasting soon after the war, leading to the establishment of this first regular station by Westinghouse, the furor over radio in 1922, and the fixing of program principles since followed. In fact we see that while radiotelephony was early foreseen and used, the possibility of its broadcast use was strangely overlooked by almost all people. Probably it was because they could not imagine the receiving apparatus as simple and cheap enough. It is hard

[12] A summary volume entitled The Future of War in its technical, economic, and political relations, translated by R. C. Long, was published in New York in 1899.

[13] By Robida, artist and editor of La Caricature, in the same for Oct. 27, 1883; reviewed as the Jules Verne of Caricature, in New Fraunce, 2: 107–110, June 1918.

[14] Clément Ader: La Première étape de l'aviation militaire en France, 1907.

[15] Waldemar Kaempffert: The New Art of Flying, New York, April 1911. The Future of Flying; in Country Life, 20: 23 ff., July 15, 1911. Aircraft and the Future; in Outlook, 104: 452–460, 1913.

[16] Sir W. H. Preece: Signaling Through Space Without Wires; in Smithson. Instn. An. Rept. for 1898, pp. 249–257, esp. 251. He later telephoned a mile by this means, and 3 miles by conduction, while wireless telephony by induction was realized by another contemporary. Cf. Sylvanus P. Thompson: Telegraphing Across Space; in the same, pp. 235–246. Thompson in 1898 was certain that wireless communication between England and America could be established either by conduction or by induction; as to radio he was less sure.

[17] Wireless Telephony; in Smithson. Instn. An. Rept. for 1908, pp. 161–195.

to find a prophet other than Steinmetz who mentioned it. But many predicted the same result by other means, and there was commercial telephone broadcasting from 1889.

Television has had a much more common and early prediction, though not achieved till 1911. (But its slow form, picture telegraphy, dates from 1847.) Souvestre [18] satirically foretold it in 1846. Senlecq [19] built an apparatus in 1877, only 4 years after the discovery that selenium varies in conductivity according to its illumination. Nipkow invented the scanning disk in 1882 and Fessenden designed a wireless system in 1901.[19] Plessner [20] in 1892 wrote a book about the possibilities of this and other future communication devices, proposing ways to combine television with the telephone for wired broadcasting, and to broadcast motion pictures, and use sound-film, picture, and facsimile telegraphy. To the uses which he foresaw for television we can add little further today, except to show the animated cartoon and its scientific brothers, the animated diagram and drawing. T. B. Russell, the present writer, and so many other forecasters have likewise talked of television, that it is hard to add anything new on the subject of this invention whose effective realization has scarce begun.

From our survey of prediction in the four fields above as well as in others, the following conclusions may be drawn:

1. War has been an unfavorable field for outside predictors, while transportation, communication, and optics seem unusually full of successes.

2. Those undertaking general prophecy have not written in the scientific manner. But no reason appears why one should not use science in estimating the future, as in any other business. A scientific worker would diligently study both the past and latest inventive developments, and comb all the best opinions and guesses about the future, in whatever language published.[28] Furthermore he would study, criticize, and improve the technique of prediction, from the evidence of past success and failure in foresight. At least no reason appears against predictive science, except the cost of labor, and the difficulty of finding special students of this field who have some acquaintance with all branches of technology and their history, and with social science, and languages.

3. Inventors are necessarily forecasters, but are rather mute aside from their own projects.

4. Distinguished technical and scientific men, who choose to predict in their own general field, make the best seers of all. Yet they are liable to upsets from developments in outside lines, and from the tendency of the ordinary scientific or technical man to see little change ahead. For these are usually much impressed with the failure of all past inventors to achieve this and that, because of supposed scientific principles that bar the path.

5. A broad view, considering every quarter from which change could come, is clearly called for.

6. There seems to be a clear case for a committee of technical men uniting their labors, together with those of social scientists and students of prediction. This has been the basic assumption underlying the arrangement of this present volume.

Why and How Invention Is Predicted

Having pointed out, from experience, that inventions can be predicted and have been 15 and more years ahead of their effective use, it would seem wise to examine the reasons why this is possible, as well as the methods of prediction that are and should be used.

Inventions can first of all be predicted because they form trends, which can be projected into the future, extrapolated as the statistician says. An important invention, like the airplane or television, is not the product of one inventive act by one heroic, titular inventor at one date. Instead that great invention is an agglomeration of a vast number of detail inventions, like the thousands that have been added to the auto. Some are inventions no longer used, like the scanning disk that for 50 years built up television. The multiplicity of these inventions brings in the law of large numbers, making possible statistics, and the predictive extrapolation of a curve. Just as a merchant whose figures show a steady growth of his business expects still more business in the future, so when we see patents piled ever thicker upon food syntheses, or see aircraft capable of landing in less and less space, or television screens growing larger and finer, we readily, confidently, and justifiedly project these trends forward a short way into the future. This is the favorite method of the more technical writers, such as in the first article quoted, and appears to give the best results for short prognostications.

As a corollary of this principle that an invention of importance is a multitudinous collection of little ones, we observe that the first start in a new line practically never brings immediate success; that many further inventions, many years and decades, and many inventors must be added to the first before full success and wide use, bearing social consequences, will be attained. This makes much easier the range of prediction commonly attempted in this volume. One sets down for the future certain inventions already started. We have seen how television began to be invented in 1877, picture telegraphy about 88 years before it attained important

[18] Emile Souvestre: Le Monde tel qu'il sera (in the year 3000).

[19] Sci. Am., Mar. 8, 1879; S. A. Sup., 11:4382, 1881. C. Senlecq: Le Téléectroscope, 1881. R. Fessenden: The Deluged Civilization, p. 123 ff.

[20] Max Plessner: ein Blick auf die grossen Erfindungen des 20. Jahrhunderts. Ferd. Dümmlers Verlagsbuchhandlung, Berlin, 1892. 92 pp.

use, wireless 15 to 70 years, radiotelephony 23, the airplane 70 or more and the talking picture 40 years, before they had any importance.

Taking 19 inventions voted most useful, introduced in 1888–1913, the average[21] intervals were: Between when the invention was first merely thought of, and the first working model or patent, 176 years; thence to the first practical use, 24 years; to commercial success 14 years; to important use 12 years, or say 50 years from the first serious work on the invention. Again, in the study of the most important inventions of the last generation before 1930, in Recent Social Trends, a median lapse was found of 33 years, between the "conception date" corresponding to the second above, and the date of commercial success.[22] Searching for exceptions, it is hardly possible to find an invention which became important in less than 10 years from the time it or some fully equivalent substitute was worked on, and few did in less than 20. Here is then, an excellent rule of prediction for the present study—to predict only inventions already born, whose physical possibility has therefore been demonstrated, but which are usually not yet practical, and whose future significance is not commonly appreciated.

This is very different from predicting future success for all present embryonic inventions. Their death rate is high—most will never be any good, like the eleven remarkable ship and engine projects of 1882, with which Admiral Preble closed his history, none of which has ever got anywhere, save for the modest success of the electric launch.

It may be useful to point out that a great reason why inventions progress so slowly through their incubating stage is that our laws provide no effective support for inventors who make basic starts in new lines. Let us cite two typical fundamentally novel inventions. A voice-operated writing machine was proposed in detail by Plessner in 1892 and Fessenden in 1907. Flowers[23] in 1916 made several such machines that would work after a fashion. But we hear of no other inventors trying to perfect the invention. Everybody's business is nobody's business, when no one can justifiedly hope to be repaid for the labor which will undoubtedly be required in perfecting the invention. An inventor may advance an embryonic art most usefully; but he can hardly advance it to the point of wide practical use, and hence he receives no recompense at all. For another example, the helicopter is needed for vertical or hovering flight, and for landing on ships, roofs, and rough places. People have been working since Leonardo da Vinci on this costly device. Some have even been flown, but no one has received a dollar of recompense except occasionally from a philanthropist or a government. Pioneer invention in new basic lines needs noncommercial support exactly as pure science does. France does a little to support and guide such inventors, through its *Office National des Recherches et Inventions*, and we have a few foundations that do something, but the costly starting of fundamental inventions is virtually unassisted, hence very slow.[24]

The second basic reason why inventions can be predicted is that they have causes. They are not just accidents, nor the inscrutable products of sporadic genius, but have abundant and clear causes in prior scientific and technological development. And they have social causes and retarding factors, both new and constant, of changed needs and opportunities, growth of technical education, of buying power, of capital, patent and commercial systems, corporation laboratories, and what not.[25] All such basic factors causing invention give means of predicting the same.

The existence and overwhelming influence of causes for invention is proved by the frequency of duplicate invention, where the same idea is hatched by different minds independently about the same time. Professor Ogburn and Dr. Thomas have drawn up a list of 40 such duplicated inventions and 108 discoveries.[26] Striking proof is offered by American patent office experience in that about half of all inventions that pass the already advanced stage of patent application are thereafter dropped, mainly because of the discovery of prior inventors, not to mention the number dropped for this reason at earlier stages. Inventors are constantly advised to keep proofs of their priority, their dates of conception. Dr. Stern has well demonstrated the abundance of duplicate discovery in medicine.[27] And certainly the observations of duplicate invention would be much more numerous than they are, did not the published fact that an invention is made, prevent others from thinking up the same thing. It is only where the two inventors worked at almost the same time, or in remote isolation from each other, that we ever hear of the invention as being duplicated.

Having thus shown by the observed and potential frequency of duplicate invention that invention has widespread causes, not confined to the genius or luck of a single, indispensable inventor, it remains to show how this wide, causative base can be used for the prediction of an invention. And this we have not learned to do scientifically. The influences from need and pos-

[21] Gilfillan: Sociology of Invention, p. 96, from Sci. Am. 109: 352. See note 24.

[22] Recent Social Trends in the United States, 1: 163.

[23] John B. Flowers' inventions are described in Sci. Am., Feb. 12, 1916, p. 174; and Fessenden's cited in R. Fessenden: The Deluged Civilization, p. 134.

[24] S. C. Gilfillan: The Sociology of Invention. Follett Pub. Co., Chicago, 1935; 203 pp. Ch. 5, The Hard Starting of Fundamental Inventions.

[25] S. C. Gilfillan: The Sociology of Invention.

[26] William F. Ogburn: Social Change, pt. 2, ch. 5.

[27] Bernhard Stern: Social Factors in Medical Progress, 1927.

sibility that point to a coming invention are so exceedingly varied in nature that it is difficult to know how to generalize about them. But everyone knows how to use them, how to reason from such bases. We say that a given situation would naturally produce a certain adaptive step, either at once, or after a certain cultural lag or delay.

For instance, we would predict the early arrival, probably within 5 or 10 years, of a stereoscopic sound effect or auditory perspective, in the radio and perhaps in phonographs and talking pictures, from the following reasoning: A need has long existed for a means of varying the direction from which sound comes, so as to give an impression of solid space, and to facilitate understanding. This need has been increased by the talking picture, the loud speaker for the deaf, the flying and detection of airplanes in fog, and presently and especially, by radio television plays. There are established trends toward better and more complicated acoustical apparatus, and a rapid growth of acoustical science, and of devices for aviation and the deaf. Fairly simple means of achieving stereoscopic sound are readily imagined, and have already been built. The resistances to popularizing and perfecting the invention are a small cost, met by a growing income; unfamiliarity and complexity, met by growing popular knowledge of physics and especially acoustics. There are also the difficulty of making over old radio sets, etc., met by the approaching need to replace them anyway for purposes of television and perhaps other innovations, the need of standardization met by the capacity of our interstate laws, and the high degree of patent monopoly in these industries. In short the track is clear for this invention.

One may note that in the above reasoning use has been made of unchanging facts, such as knowledge of magnetism; recently changed facts, such as the starting of the invention in question; assumed future events, as the coming of television; numerous trends, as toward more acoustical knowledge; influences from diverse fields—deafness, aviation and war; obstructions; and opportunities.

This complex type of prediction based on reasoning as to causation, as well as on extrapolation of various trends, is evidently far more complicated than the empirical type of prediction discussed before, based simply on the extrapolation of one observed trend. Complication makes it much the less reliable, for the short range, although the evidence may be very strong, as for stereoscopic sound. But the empirical trend method may be inapplicable, from the absence of any direct trend. In the present case, e. g., we may not know that the invention has been put to use at all, so could not establish any trend of usage.

For a longer range forecasting the complex type may be much better than the simple projection of a single trend. For any curve becomes more and more uncertain the farther it is extrapolated into the future, for geometric reasons; and trends seemingly secure, may be upset by interference from outside. For example, in 1913 the designing of bigger and bigger liners seemed a well established and secure prediction, yet because of progress in aviation and railways there was predicted a cessation of the trend about 1929. The prediction has proved to be partially correct, as explained in the previous section.

If the inferences from numerous trends and other facts converge to the same conclusion, one may be more confident one is right. If the indications be somewhat contradictory we must express doubt, or make our prediction conditional, or make none, while still perhaps predicting social effects, for reasons given hereafter.

Difficulties of Prediction

The most persistent danger, in the perilous business of forecasting, is what might be called a third regular method of prediction, to wit, sheer optimism. "Have faith, believe that what is good shall come to pass, and it shall be so" is offered us as a more or less religious motto, not only for the individual, but for society. And as Caesar long ago remarked, for the most part what men desire they believe to be easy. Man's mind normally works optimistically, save when he is out of sorts. A vast deal of utopian prophesying of the fine days to come, like Bellamy's Looking Backward, has been little more than optimism, future music. And even the best of prophets are continually beset by wishful thinking, predicting much more of good than of evil, partly because their readers will wish to hear of pleasant things. We need wireless power, or popular enlightenment, or rational costume, therefore some inventions will bring them. This method of prophecy is most unreliable; yet it has often produced good single predictions, since these were made in an age of advancing civilization, and what the predictor desired, say faster airplanes, or color movies, many inventors and their backers also wanted, and by setting themselves to discover it, satisfied at least two conditions for success—effort, with a receptive market.

Another variety of wishful thinking is overlooking the fact that the social basis for invention provides obstacles to it as well as incitements and facilities. There are all the resistances discussed in the accompanying papers against making an invention or accepting it after it is made.

While there are numerous resistances on grounds other than economics, the question of how technolog-

ical changes are to be paid for is a preeminent one. Inventions may be blocked not only because they devaluate the capital and knowledge directly concerned in that line, but also because they devaluate the accessory capital. Thus trains and tracks are tied together, so there is no future for the monorail car nor any other device that would call for rebuilding our railroads, and even electrification is held back by the great costs involved. Simply faster trains call for track improvements that cannot well be provided, so speeding can be accepted only if the train can be made much lighter.

Three other aspects of the world into which inventions must fit if accepted are tastes, customs, and laws, all very resistant to called-for changes. The sodium and mercury lamps are very efficient, but people don't like their respective yellow and blue lights. The telharmonium can play more beautiful music than was ever heard before, in the just intonation instead of the false, tempered intonation which all present instruments use by necessity. But to make the best use of the telharmonium will call for recomposing our music. Meals from central kitchens, perhaps delivered at high speed by pneumatic tubes which could serve many other purposes too, would eliminate much toil. But people like to do things their own way, which is an old way, so this prediction made in 1912 shows little progress toward fulfillment. The lie detector, universal fingerprinting, and various psychological and psychiatric discoveries, would be wonderful helps in the prevention of crime and the rehabilitation or permanent removal of criminals. But all such changes run up against the conservatism of the law. Lawyers are apt to be conservative, objecting to changes not only when they prejudice a client, but by natural tendency because their professional business is to interpret the law as it stands.

Predictors are often right that an invention can and will be made and will also be appreciated, but they still go wrong as to when, because they are too optimistic as to the reductions of cost, or of complexity. Color photography is a most attractive and valuable art that has existed for three-quarters of a century, and still it is little used except by a few professionals. The home talking picture, long predicted, is only beginning to find many buyers who are willing to pay its cost. The substitute means of entertainment or instruction are so simply and cheaply available—books, pictures, and the theater.

Advertisements tell us we can pick up our telephone and talk across the ocean to any subscriber in Hungary or Java, but for practical purposes that is impossible, because we have not the money, language, nor any need to make such calls. At any rate, hardly one in a million has, so the invention of transoceanic telephony to such countries does not yet exist as a factor of influence.

The dates of future inventions or of their use are indeed difficult to predict, because they depend on the total balance of so many separate considerations of technical difficulties, cost, usefulness, and the progress of substitutes. The stereoscopic and full-color home talking picture, with auditory perspective, could be made today and will surely come; but when will it be important?

The question is usually dodged by leaving the prediction dateless. But in a study like the present one, which aims at guidance for practical measures to meet impending situations, dating cannot be dodged. One may, however, get along with much uncertainty of dating, in two ways. First, if we know what to expect some time within the next generation, say the destruction of a certain trade, or the airplane bringing diseases in 18 hours from Africa, we may be prepared to take immediate practical steps whenever the first definite dating becomes possible, the better because we were predictively prepared beforehand. Secondly, we may be quite wrong in our prediction that such airplanes will be practical and common in 1945, and still be right in what essentially matters of our prediction, viz., that in 1945 yellow fever or other diseases will be brought amongst us from Africa and points east and west, by either airplanes, airships, helicopters, rockets, or some other means of fast traffic.

When Thurston, a good historian-engineer, predicted in 1893 that the speeds of the then 5-day liner and 20-hour New York-Chicago train would be doubled in the next generation, he was wrong—the ships sped hardly faster, and those fastest trains made the trip in the same time in 1923. But if he had made his prophecy more general by saying that through various means, traffic speeds would increase markedly, he would have been right, through the speeding up of the slow trains and ships and through the auto and airplane. We shall speak later of this principle of functionally equivalent invention, which is so helpful in predicting the consequences of invention.

Another error of wishful origin is to predict one's own invention—or rather a mere basic idea of how something can be done. It rarely happens that such ideas have value, or ever are followed with important use.

The last conspicuous source of error in prediction is sheer ignorance of the latest advances in the sciences and arts involved. This has been avoided in the present volume, so far as time has allowed, by obtaining the collaboration of able scientists, and by consulting technical literature on the various points as well as the better recent predictive writings, of which a bibliography is appended.[28]

[28] In addition to the earlier writers cited in our first section (Note 1 ff.), the following recent writings containing numerous predictions of invention seem most worthy of citation:

Predicting the Effects of an Invention

Since the effects follow after the invention, the difficulties of predicting them might seem to be multiplied, since one must risk first the errors in foreseeing the invention, and then the errors in forecasting its consequences. However, a powerful principle comes to one's aid, making it easier to predict the effects than the inventions themselves, the principle, namely, of functionally equivalent invention.[29]

Inventions are not only duplicated very often by identical solutions arrived at by different men about the same time, as noted above, but inventions are also paralleled by other, equivalent devices to the same end or effect, on other principles, perhaps utterly different principles, but coming into use around the same time. They promise jointly, though not singly, the effects which would naturally flow from such a function. If one invention fails to arrive and bring the effect, some other or others will. For instance, there are half a dozen recent means of geophysical prospecting—examining what is underground without sinking shaft or bore hole, nor remaining content with surface indications.

Sixteen different means of flying have been experimented with in recent years, of which the airplane, airship, and glider are the three most familiar.

The great bogey of flight, fog, has recently been, or may soon be conquered by some of the 25 known means. There are means contained within the aircraft itself:

Training the pilot, especially to fly by the feel of his sitting.

Instruments to show the directions and speed of flight by sight.

And by binaural hearing.

The sonic altimeter, for learning height above the ground, to 4 feet.

Seeing the ground or the sun by infra-red light, through the electron telescope just invented by Zworykin.

Trailing a television transmitter in clear air far below the plane.

Flying high to surmount clouds.

Ability to land gently on any ground or water.

Plane designed for automatic stability and no stalling.

Gyro pilot.

There are also means involving cooperation (or sometimes hostility) from the ground:

Modulated-light landing beacon.

Sound-ranging, from sounds emitted at ground stations.

Shooting smoke bombs up above the fog.

Induction guide cable in the ground.

Radio messages or signals.

Radio direction finder of ordinary type.

Radio control.

Radio beam, ordinary straight.

Radio beams adapted to lead the pilot in a proper curved path for landing.

Locating aircraft from the ground by their sound, or by radio ranging, from signals or the sparking of the engine, or by the heat of the exhaust sending infra-red rays.

Dispelling fog by calcium chloride droplets, or by projected electric heat, or by spraying electrified sand.

With all these 25 different means apparently available for conquering fog, we may quite confidently predict that by some means or other fog will be effectively overcome for aviators soon. We may be confident even though several of the 25 means should turn out to be worthless, and no others be added by future invention in this now very active field. And hence we have a firm basis for predicting the social effects of aviation without danger from fog.

But furthermore, conquering fog and determining the general type of aircraft are only two of many con-

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Footnote 28—Continued.

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[29] Gilfillan (see note 24), pp. 137–148 on equivalent invention

siderations controlling future aviation, as to its safety, regularity, speed, popularity, and utility. The total of inventions and other influences making for the progress of aviation is so vastly numerous that we might give up trying to appraise them separately, and simply consider that they are added, subtracted, and multiplied together to make up the observed total progress of aviation in the past. This total of flight history, graphed as ascending curves measuring various achievements, may be simply extrapolated a few years into the future, to show us the coming state of aviation year by year, without understanding being necessitated of how or why it will be so. On such prediction (and probably on any other kind available) our Government staked half a billion dollars, in building the Panama Canal with locks 1,000 by 110 by 41 feet, larger than any ship afloat in 1907. But this was justified by the evolution of ships during the past 30 years and by their expected development.

Even when we add together all the inventions touching aviation, including engines, better alloys, ground equipment, meteorological discoveries, etc., we have still not assembled the total inventive base on which should be erected our social predictions. Aviation's expected effects of more and faster travel, mail and express carriage, encouraging wider organization of businesses and Federal functions, more national uniformity of interests, customs and sentiments, more international contacts similarly, and a faster tempo of life—all are identical with some of the effects expected from faster trains, autos, ships, radio, television, and most of the other inventions in or affecting transportation and communication.

This again enlarged base of possible instruments makes the prediction of the social influences still more certain. The principle of functionally equivalent invention entails that the wider one's definition of an invention, or field of invention, the more certain, foreseeable and measurable become the social effects. And it is the widest definitions that matter most—what produces the total effect, the great effect that concerns people and should be appropriately met. So clear, indeed, are these general effects to be expected from technology, that they are largely well-known already. The purpose of this volume is, therefore, not so much to dwell on them, as on the somewhat narrower, more specific effects, and on inventions, as of aviation, television, and often more closely limited inventions.

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III. SOCIAL EFFECTS OF INVENTIONS

By S. C. Gilfillan

Manufacturing and Labor

The chapters of part three discuss, in more or less elaborate detail, many inventions which are likely to alter manufacturing processes and the utilization of labor in the immediate future. To attempt here a comprehensive forecast of the manifold economic and social aspects of these dramatic developments is impossible, because of the hazards of such forecasts and because limitations of space preclude the introduction of adequate supporting details. Only a few basic developments will be cited, those that affect wide reaches of manufacturing.

Indirectly, the social and economic effects of technological changes in manufacturing processes touch every phase of human life. Directly, the effects of a particular invention in manufacturing may be primarily in its saving of labor, in its saving of capital, in its improvement of working conditions, in its cheapening of the product and increase of consumption, in its improvement of the product, or in its creation of a new kind of goods. Some inventions in manufacturing may have most or all of these effects combined; other inventions may have only one or two of these effects.

The effect of an invention which seems to be most in people's minds is that of displacing labor. The usual formula for the origin of labor-saving inventions is as follows: First, a job is divided up among many workmen, and the specialized tasks of some become so simple and monotonous, like pushing a lever or feeding a machine, that, while efficiency is increased, craftsmanship is destroyed. Next, the task having become so simple, it is comparatively easy to invent a mechanical device to do it instead, and to do it better and far faster, with mere supervision by a workman. Hence, the more monotonous a job has become, the closer it has been brought to abolition. In good times the displaced worker, especially of unskilled or semiskilled, normally finds another simple job, the manufacturer sells more cheaply, and the consumer has more to spend for other things.

The monotonous jobs displaced by machines in the past have been those that could be entirely controlled by other perceiving senses than seeing. Machines could duplicate man's power to feel form, size, weight, temperature, pressure, etc., but no machine could see. A host of simple jobs like candling eggs, that required seeing, still have to be done by men instead of machines, however monotonous. Therefore, the development of a device which can see, namely, the photoelectric cell, carries with it a vast range of future economic effects. The photoelectric cell is doing an increasing number of tasks better than the most keen-eyed, skillful, faithful, and tireless workman. And it brings electrical action on what it sees, instantly, at any distance, and 24 hours a day if desired. The photoelectric cell has been set already to a remarkable variety of tasks (part three, ch. VII). It makes a particularly good combination with the vacuum tube and various automatic registering and controlling devices, making possible continuous operation and distant control. It seems reasonable to expect a rapid and wide application of this mechanism, with the results of ending many a dull job, speeding manufacture, improving quality, and encouraging multiple shifts and processes. Its use will probably have more capital than is needed for the new apparatus. The saving of labor to the manufacturer should be even greater.

Not only can machines see; they can also hear. The implications of the televox and other acoustical equipment which might be called the "electric ear" are, however, probably much less varied and important than those of the photoelectric cell. Moreover, much of the acoustical development is too near the laboratory to justify one forecasting effects with the same confidence as in the case of the "electric eye." Yet the new principle is a dramatic one. Sounds can be sifted out and selectively heard by novel devices, so that a door has been fitted to open only to the words "Open Sesame", and machinery to stop on "hearing" the cry "Help." Televox exemplifies another idea likely to have extension, that of using ordinary telephone lines to convey sounds which can actuate distant mechanisms.

It seems likely that such electrical ears and voices frequently will fit well into such complexes as have been indicated for the electric eye. They will save employment of observers at scattered posts, and listen for particular sounds which indicate how a process is going, or for sound signals. They will actuate appropriate controls, promote safety, give directions, and perhaps even distinguish individuals, accomplishments all demonstrated today. Again, there should result much reduction of monotonous jobs, and an increased demand for electricians, inspectors, and skilled mechanics instead of mere operatives.

Four characteristic trends of modern manufacturing, (1) toward continuous processes, (2) automatic operation, (3) use of registering devices, and (4) of controlling devices are conspicuous.[30] The last two may

[30] See Technology and the Chemical Industries, Pt. Three, Ch. VI.

embody the new electric eye or ear or only the older mechanical "senses." Or they may automatically make chemical tests, such as sampling furnace gas every few minutes for its proportion of carbon dioxide, to enable efficient and smokeless combustion, or measuring acidity, or chemical content by an automatic spectrophotometer. Such controls serve to improve the product as much as to save labor. One must be cautious in forecasts, however, and remember that mere technical possibility does not in itself insure future economic usefulness.

Timing devices increasingly used, the prerecording oscillograph, and numerous other machines can almost parallel powers of the human mind.[31] It appears that no limit can be set to the work which might be taken over by machinery, although the rule holds that it is the most simple and most monotonous tasks, whether physical or mental, that are the most readily replaceable through invention. While such tasks are being mechanized, new monotonous tasks are being created, through subdivision of old jobs whose product has become available for larger scale production.

Amid all the diversity of manufacturing operations, an invention with wide and increasing use is welding, by three basic methods, as well as the promising development of brazing. The results affect much more than just the direct engineering economy. The more skilled trade of welder replaces that of riveter. The fearful noise of riveting is eliminated. Metal is economized, and capital is further saved through assembly savings and the greater durability of welded products. Longer life, by diminishing replacement, tends to slow up invention. Welding, more than riveting, but less than casting, fosters neatness of form, curves, streamlining, and the new art style of metal architecture. It helps especially in the manufacture of airplanes, automobiles, high-speed trains and many other devices, mostly in transportation that especially need lightness, trimness, or permanently tight joints. Welded ships are being built. The shipbuilding trades of riveter and caulker may eventually become obsolete. By related devices, machining is being reduced by "flame machining" with the oxyacetylene torch, and metal is being cut by the electric arc cutting saw.

The work of machining is being speeded to a revolutionary degree by new, super-hard alloys for cutting tools. Machining is being further reduced by drop forging, and by the introduction of plastics, which reach final form and finish in the mold, and may enclose metal parts. New metals and alloys are being added, and the number of possible combinations of elements, proportions, and treatments increases much faster than the number of usable metals. Such progress speeds up the obsolescence of machinery and therefore may encourage in some cases the construction of machinery with less rather than greater durability. Another result is that the scrap-metal supply, which has become so important that it now contributes the larger part of some metals, is becoming corrupted with alloying metals. These elements are beneficial for many uses, but they disturb the uniformity of product always striven for today, or require expensive detection and removal or proper distribution.

The growth of manufacturing industries is dependent to a large extent on the production of cheap power. The various inventions which combine to make power show many directions of progressing economy. There are also increasing tendencies for the power to be electrical, or from internal combustion engines, and for heating to be increasingly furnished by exhaust steam (at rising pressures) from large electrical generating plants. Other developments still in the experimental stage indicate that much higher thermal efficiencies than at present will be general before many years.

Still cheaper power is not likely to be of increasing importance in the future in encouraging the use of further ordinary machinery. The wholesale power cost is already so low that the main obstacles to the introduction of new power machinery are other factors—the costs of devising, building, and perfecting the new machinery and its housing, and difficulties of selling the increased production. But important increases in power use may be expected in fields in which power or heat costs are a main factor. Such are electro-chemistry, aluminum and magnesium production, air reduction, air conditioning, large-scale lighting and ultraviolet radiation, fast navigation, and aviation. Further increased use of cheapened electricity may likewise be expected in lines in which electricity has ready rivals, especially for heating industrial and other equipment and occasional room warming. With all increased uses of electricity will come more inventions on the ways to use it. Particularly notable may be the fostering of air conditioning, steep-flight aircraft, ferrous, aluminum, and magnesium alloys, nitrogenous fertilizers, copper, and the whole strong-current electric industry.

A socially important influence of the increased use of electricity, especially as power plants tend to be concentrated into great generating stations often outside the city, is to reduce the sooty smoke in cities. The sulphur dioxide in coal smoke, however, which eats impartially clothes and paper, throats, buildings, and vegetation, is not removed by the better burning in large furnaces, but only by costly smoke purification, or removal of the plant. Numerous remedies, especially the fast-growing domestic mechanical stoker, are

[31] See Technology and the Electrical Goods Industry by Cruse, Pt. Three, Ch. VII.

available to reduce greatly the various evils of smoke, but require social enforcement. For smoke always hurts the community more than it hurts the owner of the chimney.

Among important technological improvements in the manufacturing processes are those which alter the working conditions of labor, although they may or may not replace labor. Two examples of such developments which have implications for the future are inventions pertaining to lighting and air-conditioning in factories. The increasing efficiency and economy of artificial light encourage the trend toward the use of night shifts—a trend which, of course, was interrupted during the depression. Transportation, printing, mining, and chemical and metallurgical works have long used multiple shifts, thus getting double or treble the use out of their billions of capital. The stream of new mechanical inventions, which hasten the obsolescence of machinery in manufacturing generally, encourages more intensive working than before in order to wear out equipment before it is obsolete. Transition to the two- or three-shift system is frequently retarded because workers object to the night shift, involving social isolation, difficulties of sleep, and, for women employees, housekeeping fatigues, while employers have found night work less efficient. Some of these difficulties would be lessened as night work became more general and as social institutions made adjustments to the new conditions.

Air conditioning, which was first applied in factories for the benefit of the goods, is likely to be extended gradually as it becomes cheaper and as more thought is given to the efficiency and comfort of the worker. With air conditioning also will come better insulation against noise.

One concern of manufacturing with invention has come into the public and congressional eye of late, namely, patent pooling.[32] Particularly when invention starts a new industry, the situation is apt to arise where patents, some only desirable, some indispensable, are scattered among numerous companies, with the result that none should practice the new art without the consent of others. Usually there ensues a protracted and costly series of lawsuits over patents. Finally, to end this obstruction and enable production to go ahead unhampered, using all the best ideas, either a pooling of patents is agreed to, or one company obtains a monopoly of all the essential patents. Pools have developed from time to time in the American airplane, automobile, solid rubber tire, movie, talking picture, incandescent lamp, bicycle, coaster brake, sewing machine, shoe machinery, radio, vacuum tube, and several other industries.[33] Even in the old industries, the constant arrival of new inventions keeps in the foreground the problem of the patent pool. But we are most strongly reminded of it by the prospect of new industries, based on aviation, television, phototelegraphy, air conditioning, the prefabricated house, magnesium, the cotton picker, and many other inventions discussed in this volume. There is the question of whether complete freedom of patent ownership should prevail in these coming industries and others—including the freedom of each important patentee to balk the others and fight *ad libitum* in the courts, and the freedom to organize private patent pools, such as have sometimes proved oppressive and sometimes very helpful—or whether some attempt will be made to prevent all patent pools, or to restrict or regulate them in the public interest. The fundamental problem of the working of our social institutions for eliciting, paying for, and securing early and wide use of desirable inventions has never been completely examined. It is a problem calling for a national policy.[34]

Travel and Fast Transport

Technological changes in passenger transportation usually have more direct and obvious effects on the general public than changes in the manufacture of goods, especially of producers goods. Inventions in manufacturing, even when ultimately revolutionary, usually touch the general public indirectly and in a gradually diffusive and pervasive form.

The details of various inventions in the field of transportation are treated elsewhere.[35] Since a rigid selection is necessary for the present section, the effects of changes in slow traffic, as in most freight, will not be considered. The discussion here is limited to a few of the future social and economic consequences of significant technological developments of passenger travel and fast transport of goods.

The future of air transport is a happy hunting ground of romancers and it is indeed difficult to avoid the temptation to unleash the imagination with little reference to present-day realizations. Forecasts written 20 years ago in a spirit of scientific caution,

[32] Pooling of Patents, hearings before the Committee on Patents, House of Representatives, 74th Cong., on H. R. 4523 (Chairman Sirovich's bill for recording patent pooling agreements), 4 vols., 1935–36. Also The Storm over Patent Pools: Business Week, Oct. 26, 1935, p. 30; and Dec. 28.

[33] Patent pools have existed also in the cordage, harrow, wind stacker, bath tub, oil cracking, seeded raisin, and cigarette industries, according to the authority of Dr. Warren M. Persons and F. L. Vaughan: Econ. of Our Pat. System, p. 169; Wm. Beard: Govt. and Technology, pp. 453–61 and the hearings noted above.

[34] Cf. author's Sociology of Invention, ch. VI, The Decline of Patenting, and Recommendations. A commission of inquiry is proposed on pp. 122–130. Also science advisory board: Report of the committee on relation of patent system to stimulation of new industries; Washington 1935, F. L. Vaughan: Economy of our Patent System, 1925; T. H. Low, The Inventor, December 1935.

[35] See Osgood's chapter on Technology and Transportation.

seem stupidly unimaginative today. Almost anything that can be written today in the same spirit runs the similar risk of appearing stodgy when read in 1956. There appears some justification, therefore, for using guardedly a little imagination, even though not all of the more conservative aircraft engineers of today would accept the conclusions. On the timing of these inventions especially, we may err. But certain previsions seem realizable with a high degree of probability, though it is very hard to say whether they will take place in 10 years or 40.

For fast transport of passengers, mail, and express over long distances, aviation is, of course, the preeminent field of anticipation. Superoxygenation of the air, already practiced in some passenger planes, or pressure cabins, can make up for thin air in high altitudes. Long distance flights may be considerably helped by modifying the gasoline or by use of Diesel engines as in German trans-Atlantic planes. Reciprocating and turbine steam engines are also being further improved. The Diesel engine is heavier than the gasoline one, and therefore less suitable for short flights; but its obtaining 30% instead of 20% of the energy of the fuel may some day favor it for long flights, as soon as its reliability is assured. Its safety against fire adds to its advantages.

For flying on regular and year-round schedules across stormy and fog-bound polar and temperate regions, better navigating instruments will be needed than are now available. But at the present rate of progress they should soon be supplied, and planes will be large enough to carry them easily. Already invented are the radio guidance and control and the automatic gyro stabilizer and pilot, that needs no eyes and makes no mistakes about flying angle. Other means of combatting fog, 25 in all, have been proposed. Better organization of weather and radio service, with automatically reporting radio polar and ocean stations (pt. three, ch. I) and higher flight possibilities, should make it possible to dodge storms. The conquest of ice formation is progressing. Multiple engines make forced landings because of engine trouble very rare.

In anticipation of air and radio needs, all over the world the nations are seeing a new importance in little, unproductive, forgotten islands, like Clipperton Island, disputed recently by France and Mexico, between Hawaii and the Panama Canal; and like Howland, Baker, and Jarvis, south of Hawaii, to which we have recently reaffirmed our sovereignty. If there are other islands or reefs unoccupied and unclaimed, whose foreign occupancy in the future might become disadvantageous to us, it would be possible for the United States to occupy them with crewless radio stations. These stations, incidentally, could continually report the weather. Similar radio sending stations will be needed in the Arctic to serve meteorology, especially if intercontinental airplanes begin to use the shortest great circle route over the polar regions.

In addition to polar land and Pacific islet stations, floating stations may be established farther south in midocean, according to various plans which have been advanced, and one put in practice. All such stations, floating or on islands, will involve new problems of inter-company and international cooperation. For unduplicated bases are clearly called for; furthermore the same routes that serve commerce might serve bombers.

All trans-Atlantic flying will greatly speed mail, passenger, and express traffic, especially in connection with overland flying to complete the journey. Tours and brief oversea visits, especially by people who prize their time more than money, will be particularly encouraged. The possibility of getting a letter from a distant home regularly in two days will also encourage ordinary tours and business travel. Today, with the infrequency of mails, the time usually required is much more than the seven days or so nominally requisite.

But the social and economic changes to follow the shrinking of the globe by long distance aviation are, in some respects, less significant than the changes in habits of life which would result if the promises of steep-flight aircraft come to realization. Expert opinion is divided; every word here written about such craft as the helicopter and the autogiro must be read with the reservation that many years may elapse before the technical problems, such as that of providing adequate forward speed, have been solved. Yet the winged horse which could leap into the air, soar or hover in the skies, and drop gently to a constricted landing spot, is no chimera—experimentally, at least, it has arrived.[36] The familiar autogiro has recently been developed on an experimental basis for a take-off with

[36] De la Cierva's recent autogiro, able to leap into the air, fly away, and land almost vertically with a run of a few feet, is discussed in Scientific American 152: 317, 1935; and with the gyroplane, vertaplane, and "roadable" autogiro in R. M. Cleveland; Wings That Turn—possibilities of rotating wing aircraft—vertical rising—high speed—roof-top landings; in Scientific American 153; 32, 33, 1935. Cf. also Autogiro, Rebirth; in Fortune, 13: 88–93, March 1936. The helicopter and other types are discussed by E. Teale: Planes That Go Straight Up Open New Fields for Aviation; in Popular Science Monthly, June 1936, pp. 31 ff. One type of steep-flight craft depends on planes set in the horizontal propeller blast. The paddle-wheel type of Rohrbach or Platt has feathering blades revolving about a parallel, horizontal axis. Another type has propellers with large blades of constantly re adjustable pitch, the shaft directed downward and backward and a small airplane added. Dr. A. F. Zahm's orthoplane plans are given in Scientific American 153: 268. All steep-flight craft, like airplanes, depend on the lift from airfoils (planes) moving swiftly and almost edge-on. They differ from airplanes in that they can maintain this swift motion and strong lift even when the body of the aircraft is moving slowly, because their wing planes rotate. Preferably they can also maintain the rotation from the energy recovered during a descent, in case of engine failure.

no run at all. The helicopter, which screws itself into the air, first sketched by Leonardo da Vinci, has been made to rise and fly about under control, although its flight is as yet only a crude beginning. And there are other types, for example, the vertaplane, which is a biplane whose upper wing is rotated for reconnoitering and landing but fixed for efficient ordinary flight. It has flown experimentally in both forms.

The consequences to aviation and civilization, from the power of landing and taking off almost anywhere, promise to be immense, multiplying the usefulness and safety of aircraft many fold. Almost all of the globe would be open to air traffic, including the places today least accessible to fast land or air transport, such as wildernesses, mountains, ships, and city centers. The present airplane type doubtless will continue in use for high-speed, long-distance, large-unit traffic; steep-flight aircraft may be expected to supplement the airplane, not to supplant it. For example, the highest paying demand for aviation is for transporting passengers, mail, and express between the centers of great cities. The slow trip through crowded streets to the airport at the edge of a city is a drawback to long flights and a preventive of short flights. But the "roof-hopper" would know no such difficulties. The new Philadelphia postoffice has a roof planned for aviation. If it will soon be practicable to put passengers or mail aboard a steep-flight aircraft in the center of a city and fly to a suburban airport on cheap land in a few minutes it may not be worthwhile today to build airports and buy expensive land near city centers.

Aircraft, being light, could be housed on roofs, or the folding ones brought to the next lower floors on elevators. If aircraft were everywhere, like taxies and trucks, they could be vastly convenient. Modifications of architecture might well be entailed. The fog difficulty is yielding to science. Steep-flight aircraft could be far safer in traffic than an airplane. For by definition it is capable of slow, and of steep or vertical flight, and perhaps of hovering and going backward, and of landing almost anywhere in emergency without injury to itself or to the buildings or people beneath it. Such aircraft will have more freedom of movement than our present automobiles, since they can move in three dimensions instead of two. And they will have much more control than our airplanes which must rush unstoppably ahead while in the air.

With the increase of aircraft, national and State boundaries and physical walls will mean less to the lawbreaker. While some police operations, especially in a rugged terrain, would be aided, some offenses, such as smuggling and the conveyance of illegal immigrants, promise to become easier when aircraft flying and landing are such everyday matters that they do not attract notice. The increasing ease of illegal entry into the country may stimulate demand for legislation requiring identification cards for all foreigners.

The cheap, safe airplane for amateurs, whose invention our Department of Commerce has been encouraging, is advancing more slowly than some enthusiasts had hoped, but eventual success seems certain. While private planes within another decade probably will be used by the ten-thousands, more time doubtless will elapse before they become serious competitors to the private automobile. The steep-flight principle, with its adaptation to landing on one's own office roof, back yard, or favored spot for recreation, and with its relative safety, may some day provide the most popular aircraft for amateurs. Types of autogiro or airplane already demonstrated, which can land on any usable field, fold up like a beetle, and proceed along the highways like an automobile, to be housed in the home garage, have intriguing recreation possibilities.

Automobile transport, aided by constant technological improvements in automobile production and in highway design, may be expected to continue its work of increasing mobility, destroying provincialism, speeding suburban growth (with the steep-flight aircraft for more remote suburbs), and spreading urban ways of life and thought throughout rural America. Incidental byproduct effects are likely to be numerous. To mention but one example; the lighting of highways with sodium or high-pressure mercury lamps, if it proves extensively feasible, not only would help safety and provide 24-hour capacity for highways, but also would fit in with a rural electrification program, since the same costly line can serve the highway and the adjacent rural areas.

The new development in motor transport which has the most direct social and economic possibilities is, however, the house trailer. The trailer may be a passing fad, but the odds are in favor of a rapid and persisting development. A highly mobile population of problematical size may be created, in which the traditional home, which has its roots in a single locality and is controlled by neighborhood *mores*, may be abandoned, yet, at the same time, family solidarity may be fostered. Along with the freedom to follow the seasons for occupation and for pleasure would go certain losses, especially to children who may suffer breaks in schooling, in friendships, and in community loyalties. Insofar as the trailer becomes a permanent residence of a household, its limitations of space would possibly encourage the trend to smaller families. The service institutions, such as campgrounds and filling stations, must enlarge their functions, since a trailer is not suited for crowded streets

in the city shopping area. New problems of government seem likely to arise, relating to taxation, car registration, police and sanitary regulations, and establishment of place of residence for voting. More interstate uniformity of the laws affecting travelers may be called for. The trailer, when mass production leads to cheaper prices, is likely to supplement rather than replace the stationary home.

In the railways we find a vast industry that lagged in applying new technological aids, but is now making striking moves to match its competitors. Bus coordination, motor-rail cars for local service, faster expresses, electrification of the few most used lines, and the introduction of new luxuries will help the fast traffic. But the mileage of lines abandoned, and of those used for freight only, is expected to increase, and tendencies to be strengthened toward consolidation of roads and terminals, for economy, and because there are no longer new empires ahead to compete for. Electrification and dieselization of terminal traffic are making cities less smoky and noisy, and may tend, as in New York, to bring leading business districts nearer to the railway station. Faster and much longer runs by all kinds of locomotives tend to undermine the "division point" type of town.

In water-borne traffic the increase in steamboat speed is and will be slow, that on the Hudson River having hardly been increased in a century. Hence goods calling for rapid transportation are no longer shipped on our inland and coastal waters, nor passengers, save where recreation enters. And now fast ocean traffic is meeting increased competition by rail and air. For now there are rail and air lines across and along Asia, Africa, and South America, air mail across the Pacific and South Atlantic trans-Atlantic dirigibles, and probably there will shortly be passenger and mail airplanes across the North Atlantic. It seems likely that much fast traffic over water will go by plane within 10 years, as happened long ago with gold shipments across the English Channel.

Ocean ships will be safer, through perfection of many minor inventions for fire protection, echo sounding, etc., and especially through means for overcoming fog, the principal source of the remaining marine disasters. Seventeen of the 25 different remedies against fog listed for aircraft are applicable, with modifications to ships. Usually they are easier to use afloat, since the ships can contain, pay for, and take time to use more apparatus. Particularly promising and perhaps some day needing legislative enforcement, are the uses of infrared light, with the electron telescope, for sighting through fog the sun, the signal lights and hot funnels of an approaching ship, and lights or special signals from lighthouses. Lighthouses and fog-horn stations may eventually be transformed into radio, infrared, and underwater sound stations.

A major social significance of all inventions for travel and fast transport is that they serve also for communication. The people who travel, as tourists, businessmen, and immigrants, carry the ideas of one region to another. Swift movement of goods is commonly of letters, printed ideas, examples of art, or highly manufactured goods which serve often as samples or suggestions. National business and political organization, as against local and State, with the accompaniment of national ways of thinking, are built up by every improvement of long-distance transport and communication.

Entertainment and Education

Few inventions have captured the imagination more than those which seem destined to alter habits of life and social and economic institutions associated with entertainment and information. The wonders of motion pictures and the radio, now commonplace, would have appeared to an earlier generation as adventures into a world of magic rivaling or outdoing the bizarre dreams of ancient fairy tales. Today, with the imminence of television and other inventions in the field of communication, there appear before us new wonders which even within our own lifetime, seem likely to become commonplace.

The recent technological progress in communication will be described in chapter IV, part three.

Principal attention will be given in this chapter to television,[37] while other inventions and their possible effects will be discussed very briefly. Television is of such great popular interest that it seems worthwhile to consider carefully, yet somewhat boldly, some details of its expected impact on American life.

In ordinary life the eye is used more in perception than the ear. It has been suggested, therefore, that visual broadcasting when perfected will have even more important social effects than aural broadcasting. Such an idea must be accepted with caution. From the social standpoint, the most significant development took place when the radio made it possible to send news, music, and propaganda through the air into the home. Six years ago, the authors of the chapter on "Invention" in Recent Social Trends were able to list 150 social effects of the radio in its aural form. It does not seem likely that television will introduce a new list of social effects which is longer or more important. Addition of sound to pictures doubtless produced relatively few new social effects of the cinema. Addition of pictures to sound should be more important in the case of the radio, because of the greater

[37] See all ch. IV, pt. Three.

use of the sense of vision than of the sense of hearing. Yet it is likely that the main impact of television will be to intensify the social effects which broadcasting already is producing.

The probable uses for television were pretty well foreseen by Plessner in 1892, when he wrote that it would present the stage, opera, important events, parliament, lectures with demonstrations, church services, visits to watering places, races, regattas, parades, city sights, and the head of the state addressing the whole nation on opening parliament or declaring war. To this prevision of 44 years ago modern civilization has added advertising, movies, the animated cartoon and drawing, and new sports.

It seems reasonable to expect that the most popular type of entertainment by television will be the drama. The drama may grow in importance at the expense of music, which, not requiring the sense of vision, has occupied such a large share of aural broadcasting time. The motion pictures, rather than the legitimate stage, doubtless will provide the dramatic patterns, since the televised drama need not be limited to the walls of a single indoor stage and since the same variety of scenes, close-ups, angle shots, and the like can be achieved in television as in the cinema. The competition of the home theater with the moving picture theater may lead to important economic readjustments, rapidly or gradually, depending on the enlargeability of television screens, the abundance of televisors in homes, and on the controlling of patents and programs. The motion picture producers are not likely to suffer so much as the exhibitors, since it is likely that most television programs will be recorded as talking pictures before being broadcast. The advantages would be to gain time for careful staging, facilitate repetition, permit simultaneous presentations without the difficulties of long-distance television transmission, and make easier adjustment of programs to local differences of time, taste, and advertising demands.

As the visual drama enters the home, a strict censorship against anything markedly objectionable to numbers of people doubtless will be imposed, following the example of radio programs, which may be stumbled into by any person, including children. Indeed, an even more drastic censorship seems likely than in aural radio, since there will doubtless be fewer broadcasting bands for television. Due to their necessary great width in the spectrum, there will be, it appears, only one or a few television bands for each city. As the progress of invention heightens the perfection and detail of television, e. g. adding color and stereoscopy, one would infer that the wave band must widen. Unlimited entertainment programs will be offered and open to such a powerful medium; from these a select few must be chosen, and planned to the last detail. This is not formal censorship, but the necessity of selecting only a few among the many types of programs available might produce essentially the same result. If the management sells time on the air to the highest bidder, more freedom from censorship of the drama might prevail than if some other principle of financing programs were adopted. Yet an advertiser in his own interest would probably tend, as at present, to avoid giving unnecessary offense to prospective customers.

The televised drama has vast potentialities of utilization for political campaigns and advertising promotion.

Of course, political addresses will be more effective when the candidate is both seen and heard and is able to supplement his address with charts or even motion pictures. Good looks and presence will help, but success frequently may tend to favor those presenting the most skillfully managed professional shows, rather than the candidates best at radio talking, or at going about his constituency, or at capitalizing a loud and durable voice in speech-making. An advertising morsel may be woven into drama, as into other radio offerings today. Although trade associations could use plays better than single firms, television is likely to be a powerful sales medium for a wide variety of businesses. In addition to the drama, straight sales talks can be most effective, in which goods are displayed, even under a microscope, and turned over to show the trade mark and the manner of using, while the salesman orates in the background. An evening telephone staff might be on hand to receive orders and perhaps to show further goods by point-to-point wired television. If informal agreements and consumer pressure do not operate to keep sales talks within bounds there may be new demands for government action. The limited number of bands available for television should tend to strengthen powerful firms with large funds for advertising, at the expense of smaller concerns.

The use which newspapers will make of television and radio phototelegraphy in supplying news bulletins and pictures to the home depends on the availability of broadcast bands and on the extent to which wired as well as radio television and phototelegraphy will be cheaply available is used. Facsimile news bulletin could supplement the oral report by the present radio, while the opportunity to broadcast pictorial news, bringing scenes of sports events, state occasions, or disasters directly from the place of occurrence would afford a striking innovation. The transmission of whole newspapers (or parts of newspapers giving the national news) by wire facsimile telegraph, from chain newspapers headquarters to provincial newspaper offices, is described in chapter IV, part three. It

will have the effect of strengthening metropolitan and chain newspaper influence.

Thus far have been considered some of the implications of television as broadcast by radio into the home. Television should also be expected to be widely distributed by wire: how widely will depend on whether the ordinary telephone wires can be used, or only special wires. By wire will be broadcast all sorts of visible entertainment not sufficiently popular to win the very scarce broadcasting channels, but which could pay for themselves through charges for the wire service. These would supplement the radio programs. They would be received in small theaters, hotels, clubs, restaurants, and billiard rooms, in homes able to pay for them, and in schools. Censorship will be less important with this wired television than with radio, if many programs can be available at once. One of the most significant probable uses of wired television, from the standpoint of social effects, needs more detailed treatment, namely, the role it may come to play in the school.

Although education is one of our major activities, with a fourth of the American population attending school and with a budget which uses up more tax money in normal times than any other single outlay, education has been slow to adopt mechanical invention. The phonograph and radio have been used considerably in teaching music, and the silent motion picture has been used here and there for pedagogical purposes. The expense of educational talking pictures, especially animated drawings and dramatizations, together with the notable lack of organization among schools to absorb what necessarily must be a large-scale output, has limited the production and utilization of films such as the University of Chicago has produced in the sciences and Yale University in American history. The public schools serving four-fifths of our population are managed on a town or smaller district basis, and comprise over a hundred thousand separate public-school administrations, beside great numbers of colleges, parochial and private school organizations. Naturally it is difficult for all these authorities to agree sufficiently to bring about the production and easy distribution of expensive films. And the films must remain expensive so long as their costs must be assessed upon few users. Wired television, however, will have the power of carrying such educational talking pictures directly into the school room, with probably less expense. The only drawback, once the technical problems are solved of presenting on the screen an image large enough and clearly enough defined to be seen by a classroom would be that many schools would need to adjust their schedules to tune in at a uniform hour. This would seem like a simple adjustment, yet one must not be too sanguine about the highly unorganized schools awakening at once to the new pedagogical opportunities.

One must be cautious about predictions from knowing how slow the schools have been to adopt other mechanical teaching aids. Yet may one not imagine for a moment what might be done, if the average elementary school teacher, instead of talking herself about the lesson or depending on the textbook, should step to the rear of the classroom and switch on the televisor, or a talking moving picture program? By it she could present to the children a speaking, colored, moving, perhaps depth-showing image, strikingly lifelike, of one of the best teachers in the land, of a great scientist performing experiments as he talked about them to the children, an artist drawing, and explaining why he drew as he did, a musician, statesman, inventor, capitalist or handicraftsman demonstrating his work. The performance would have been carefully prepared in collaboration with education specialists, to be as interesting and effective as possible for children of just that school grade. The animated drawings and movies already produced for schools and sometimes used in them, far exceed the specific pedagogic powers of even the best teachers in science and art. They telescope into a few seconds, millions of years of geologic time, make the movements of gases and electricity visible, present explosions without doing damage, gather the four corners of the world, with their living, singing people, into each classroom, and make the past live again in the present, in moving dramas of history.

How long it would be before such a prospect could be realized on an extensive scale no one can tell. Gradually, however, the use of television, as well as the radio, direct talking moving picture, and phonograph may be expected to reach out farther and farther, from schools in metropolitan centers to those in smaller communities, from colleges and high schools down to the primary grades. Among the general influences might be the following: (a) An increase in cooperation and interschool organization; (b) more attention to the sciences, social studies, and the arts, growing subjects in which the machine is best fitted to supplement the average teacher and textbook; (c) greater influence from the intellectual elite in contrast to the poorly trained provincial teacher; (d) extension of adult education, since the same programs used in the schools might be desired for leisure use in the home; (e) increase in the danger of propaganda invading the school system.

An important question may be raised as to the possible effects of television on motion pictures and music. With respect to movies, the previous discussion has indicated that television is eventually likely to depend extensively on broadcasting of motion pictures, with

the possible strengthening rather than weakening of the position of the movie producers. The movie exhibitors face definite competition, however, from the home theater. This competition should provide an added stimulus to the early development and utilization of inventions for the improvement of the direct, not televised, motion picture. The two lines of development which would appear to give the movie houses a marked superiority over the home theater, at least for a considerable period of time, are color photography and stereoscopy. Color photography is steadily improving, while stereoscopy has not yet emerged from the experimental stage. Stereoscopic movies, based on various principles, some without special viewing apparatus, have been produced by the Bell laboratories and others. A recourse which may or may not be useful is the novelty polaroid, the first glass or other transparent material available in large pieces which can polarize light. Although the first full-color stereoscopic movies already have been produced experimentally, with startling realism, there are two drawbacks, namely, much of the light is stopped and the viewer must wear polaroid spectacles. Color and stereoscopy may be largely confined to the movie theaters for a time, but it seems reasonable to expect that the problems of adding these features practically to television will be solved eventually.

Music, as has been indicated, probably will yield some ground to the drama when television becomes general. Yet television may not be wanted much in day-time entertainments, especially when the listeners are women busy with housework, and the aural part of a television program could still be listened to without having or using the visual apparatus. Sight cannot add much to music. The beauty and fidelity of radio sound, with or without television, is being improved by inventions giving a greater range in overtones and loudness, while the reduction of extraneous radio noise, automatic volume control, reduction of fading, and improvements in remote control will add to the pleasure of hearing musical broadcasts. The addition of stereoscopic sound, if current experimental success bears further fruit, will add to the realism of radio music and of phonograph music as well, but be chiefly useful with television drama. Progress in music also is fostered by various other electrical inventions, which have produced organs of novelty and beauty with the power of playing as loud as one pleases or so softly as to be heard only by earphones. The whole character of music may, indeed, some day be directly influenced by a new musical instrument, still in the laboratory, with 144 notes per octave, which is able, like Cahill's telharmonium, to play in the just instead of the false, tempered intonation, and which contains Cahill's and Fischinger's principles of variable tone and synthetic sound.[38] Ideal tones could first be designed as waves on paper, then sounded, making unnecessary the dependence on tones which our voices and ancient instruments can furnish. While the future of music is alluring, television doubtless will intensify the trend already begun by the radio and talking picture to reduce the number of professional musicians, permitting a greater concentration of rewards to the excellent few.

Acoustical progress fostered by entertainment needs and World War inventions, has led to many developments in the musical loudspeaker and phonograph fields, and in particular to a growing attention to noise prevention. The study of fatigue also has been leading to claims that noise contributes to fatigue, neurasthenia, deafness, and loss of efficiency. At the same time noise is tending to become worse, with the growth of cities, of power consumed, radio in autos, advertising loudspeakers, aviation, and the need of protecting more daytime sleepers. Noise can be prevented by so many different basic principles and particular applications of them,[39] that the progress to be made will evidently depend not on individual inventions; but on the general desire for quiet; legislation to demand quiet; wealth to pay for it; and on the progress of measuring devices and basic science.[40]

When to the spoken word is added the living image, the effect is to magnify the potential dangers of a machine which can subtly instill ideas, strong beliefs, profound disgusts, and affections. There is danger

[38] For Oscar Fischinger's work on synthetic sound see Pop. Sci Mo., Mar. 1933, p. 36; or Les Ornements Sonores de M. Fischinger, in *La Nature* 60: pt. 2: 437–9, Nov. 19, 1932. On the telharmonium cf. E. H. Pierce: A Colossal Experiment in Just Intonation; in Mus. Quarterly, 10: 326–32, 1924; and R. S. Baker: New Music for an Old World, McClure's Mag. 27: 291–301. The invention is now being worked up to originate the notes through film discs or other means much easier than Cahill's dynamos.

[39] Noises can be prevented by stopping an unnecessary noise before it starts, or by changing an especially distressing sound element, or by tightening machinery to prevent useless vibrations, or by streamlining, or by slowing the tips of an air propeller. A noise once started can be cut off by separating a sound-carrying connection, or the noise may be imprisoned in a hood, or caught and deadened by a soft surface, or entangled and broken up by baffles or a filter-like glass wool, or reflected away.

[40] Some devices may be mentioned that will most likely be used for quiet. Rubber is increasingly used in all sorts of machinery, streetcars, airplanes, flooring, pavements, and even horseshoes. The means of insulating rooms for sound fit in admirably with the tendencies to insulate them from heat and cold, for air conditioning, and with the use of artificial ventilation, light and ultraviolet. For deadening sound, loose materials, like celotex, and soft materials like boards made from cornstalks, straw, etc., are often needed, made of agricultural wastes, although not fireproof. All of these are much easier in new construction than in rebuilding, so the day of soundproofing will not come till building resumes. Household electric appliances like vacuum cleaners and fans can be silenced, and may need public-official attention at the same time on account of radio disturbances, especially in the day of television. Welding instead of riveting is a great noise saver, especially in the most populous districts, but sometimes its use needs legal permission. Welding has nowhere been yet required in building. A new street car invented for half a million dollars, put up by 25 street car companies acting together, is so silent that the trolley wire noise is the principal one left; and the car is much improved otherwise.

from propaganda entering the schools, and perhaps much greater danger from the propaganda entering the home. How great is the power in the control of mass communication, especially when helped by modern inventions, has been made clear recently in countries that have had social revolutions, and which have promptly, in a very short period, brought extraordinary changes in the expressed beliefs and actions of vast populations. These have been led to accept whole ideologies contrary to their former beliefs, and to accept as the new gospel what many outsiders would think ridiculous. The most powerful means of communication, especially for rapid action in case of revolution, are the electric forms like radio and television, which spread most skillfully presented ideas to every corner of the land with the speed of light and a minimum of propaganda labor. Compared with these the impromptu soap-box orator with his audience of a dozen, or a local preacher with his 200, are at a grave disadvantage. Certainly no advertiser would expect to sell as many goods by an amateurish appeal reaching 10 dozen, as by a captivating one reaching 10 million. Television will have the power of mobilizing the best of writers and scene designers, the most winning of actors, the most attractive actresses.

A fundamental question of national policy is therefore raised. What ideas, whose ideas, shall be mass-communicated? Who shall control television? To control the doors to people's minds, even of the child in the home, is to have considerable power to control their minds. Whatever body wields such power might conceivably be able in time to undermine all opposition to its power. The question is evidently raised whether the control should be in the hands of private capital, presumably under Government supervision, or under direct Government management and control.

A vital aspect of this problem is the patent situation. The British Government has met this problem by demanding a pool of all British television patents. If they were not pooled, patent holders might block one another. In American television, the high degree of monopoly and cooperation already existing in radio and elsewhere in the weak-current electric field may perhaps be considered as paving the way for pooling satisfactory to the public interest. Two things seem sure—that we shall not help matters by letting producers balk each other with patents, or spend millions fighting over them; and that there are great technical economies in permitting the weak-current electric industry to remain an integrated whole. Particularly with the wires, where the same wire can carry simultaneous telephone, telegraph, ticker, telephotography, and chain broadcasting messages, and the same line of poles can carry all the electric communications between two cities, it is logical engineering not to start duplicating the lines.

Akin to the patent and control problems is the need of a standardized but improvable electrical system, so that any receiving-set owner may receive any broadcasts within his reach, and continue to receive them for years despite improvements added, such as finer definition. Nation-wide standardization of apparatus is also desirable so that large-scale manufacturing could reduce the cost of making and servicing the sets.

International standardization is desirable with Canada and middle America, and maybe some day with Europe, but not, it appears, in the present short-radius stage. Along with international standardization and regulation, some enthusiasts have foreseen a need for an international language, such as the easy and neutral Esperanto which has been used by several international radio organizations. But the day when such a need will be generally felt still seems distant.

For good or for ill, a new day is dawning in entertainment, and eventually will dawn in school education. Technology has provided the power to enrich the leisure hours, to promote family solidarity by bringing the theater into the home, to develop national uniformity and unity at the cost of provincialism, and to widen man's knowledge of the world in which he lives.

Some Agencies of Control

Inventions Affecting Law and Order

Numerous inventions, both technical and social, are being developed as an aid to law enforcement. But many of these inventions have a much wider potential effect in creating order and regularity in the community as a whole. At best, in the modern scene, we can hardly know our fellows as well as in the older, stable village community. For the increases of population, cities, and mobility between residences, cities, and jobs, and the swift passage by auto, make it harder than ever to tell whether our neighbor is a man to greet, shun, elect to office, arrest, employ, or discharge.

The polygraph,[41] commonly called "lie detector", does not automatically detect lies, but does enable a highly trained user to detect emotion aroused by questions, and so usually to determine guilt or innocence, and to learn whatever facts the suspect is trying to conceal, providing the expert has some notion of what to ask and the suspect can be prevailed on to take the test. The polygraph of Prof. Leonarde Keeler is a device which measures blood pressure and respiration, while carefully chosen questions are asked,

[41] Keeler, Leonarde: Debunking the Lie Detector; in Jol. of Crim. Law; 25: 153–9, 1934. Inbau, Fred E.: Methods of Detecting Deception; in Jol. of Crim. Law; 24: 1140–58, 1934.

some harmless, some fitted to arouse emotion in a guilty but not an innocent person. While the guilty person tries to control one symptom, e. g., his breathing, he gives himself away by others.

The polygraph, in thousands of cases under the direction of Prof. Keeler, has proved highly successful. It met rapid acceptance from the police of Chicago and neighboring cities, and from 45 different Chicago financial institutions in the years 1931–34. In police circles it has been useful for obtaining confessions and evidence, freeing innocent suspects, and saving time of detectives by terminating false leads.

This invention does not come alone. As per the principle of functional equivalents it comes paralleled by three or more other means of reaching the same end—notably scopolamin, sodium amytal, and hypnotism. Scopolamin and sodium amytal are drugs which, while they have been applied with successful results [42] by medical experts on various types of prisoners, nevertheless encounter a great deal of opposition both on professional and ethical grounds. Similarly, the use of hypnotism is subject to widespread objection.

Nevertheless, the third degree as a means of lie detecting is being displaced steadily by the many new, humane, and scientific means, though many police departments still cling to the third degree from habit, lack of information, and the general conservatism of our legal system as a whole. As yet any defense lawyer can object to these new devices. Their proponents have hitherto avoided asking their acceptance, either by courts or legislatures. There are no controlling decisions, and the devices have never been used to prove guilt directly and legally. But they are useful in getting confessions and other evidence, in freeing innocent people; and have been successful also in private business. Their proponents delay asking appropriate legal changes until their case is not only conclusive but also widely known, as when the capacity of fingerprints to prove identity became well known.

Identification.—Numerous scientific inventions will facilitate the identification of individuals, whether dead, mute, or lying. The chief one is fingerprints, by no means a new invention, since the Chinese have long used it for documents and bank notes. The new silver nitrate method of raising latent fingerprints from paper, cloth, and rough wood, and even revealing a print made through a glove, should increase their police usefulness. The Federal Government has now the prints of 5,000,000 people at Washington, and is receiving 300 a day sent voluntarily by people appreciating this protection in case of impersonation, desertion, kidnaped or wandering children, amnesia, death, loss of mind in a strange place, or a general disaster. Some banks use the fingerprint in lieu of signature by people unable to write, or require it from all visiting a safety deposit vault. It is expected by some that insurance companies will soon unite in demanding that all policies be fingerprinted both by the insured and the beneficiaries. The prints would be similarly useful on wills against impersonation. The recent discovery that fingerprints can be effectively forged will require caution in accepting prints of people other than the person offering them. But a print made on the spot, with a bare finger, cannot possibly be false.

Argentina takes the prints of all males reaching 18, and gives an identity card to any person of good conduct who asks for one. In the United States the facilities for gathering of official prints have been increased not only by voluntary offering but by taking them for all World War and other soldiers, Federal civil service employés, postal savings depositors, and most offenders. The new millions of old age pensioners, relief clients, and would-be immigrants offer wider possibilities if fingerprinting should grow in the future.

Various other bodily characters have been proposed as substitutes for fingerprints—toe prints, which mirror those of the person's fingers, footprints, fingernails, and the capillaries on the retina of the eye. But none are so convenient for universal use as fingerprints which are not likely to be replaced. But from time to time they will be supplemented, as by a file and catalog of handwritings, voice records, and a criminal's "modus operandi", portrait, regular description (portrait parlé), and a talking picture showing him in normal activity. All of these are beginning to be used.

A new development which increases the need for such identifications is plastic surgery, to which major criminals have recently turned. By modern facial surgery the profile of nose, forehead, and chin may be widely altered, the ears, especially trusted by police, changed completely, the face "lifted", and old scars, birthmarks, and tattooing removed. This is done usually with no conspicuous new scarring, though close looking and feeling will reveal it. For the final capture, a man must usually be recognized by sight, however well his fingerprints and other traits are known; so plastic surgery remains a new problem for the police, and for voluntary and perhaps obligatory precautions by the surgical profession.[43]

The identification of criminals by relics they leave behind or carry about them is a rapidly advancing art, which tends to reduce crime and may transform police departments, as soon as the inventions spread more

[42] Inbau, *supra;* and Time, Nov. 18, 1935. Inbau and Lit. Dig. Feb. 15, 1936, p. 32.

[43] Maliniak, Jacques W.: The Plastic Surgeon and Crime; in Jour. of Crim. Law, 26: 594–600, 1935.

widely. A hair, a match, the dust in a man's pockets, the dirt on his shoes, may through scientific study become crucial clues. Moulage enables preserving for years a perfect cast of an impression left by a hand, foot, teeth, or a burglar's tool, or a lifelike reproduction of any perishable object.

The identification of bullets and firearms by their individual grooves is becoming well known; the like may be done with burglar tools. Serial numbers filed off a gun, auto engine, or some stolen article may be brought out again. Blood stains that have been washed for concealment can still be distinguished, by two methods, from any other stain save that of blood from a human being or a great ape. With a better sample, and the new technique of Zangenmeister, a single individual's blood or even a fingernail may be used for identification. The standardized description of a criminal seen, and his habitual dress and behavior, have recently come to be cataloged on punch cards, so that all the people showing a certain combination of traits can rapidly and mechanically be sorted out.

Handwriting is a clue to identity often available, and may reveal to a special student whether a hand was disguised and often what are the characteristic features of the writer's own hand.[44]

All these and many other developments in scientific criminology are creating a situation where a police personnel capable of using them can do far better work than an unintelligent and untrained staff. The recently established United States Police School covers in 12 weeks 77 different subjects, including photography identification of typed and handwritten documents, elementary chemistry, drawing and charting, finding and developing latent fingerprints, glass fractures, gunpowder tests (e. g., to tell whether a man has fired a pistol since he washed his hands), recording crime-scene data, toxicology, statistics, records, spot maps, uniform crime reports, firing from autos, bobbing and moving targets, gas grenades, flares, abnormal psychology, and expert testimony. Postgraduate specialized courses are also given.

Another consequence of the elaboration of police methods is the impossibility of a village, town, or county police force having all the equipment and experts, and especially the identification files, that may be needed. Scientific progress brings a strong tendency, therefore, for our 39,000 separate police agencies to establish closer connections with others in their State, Nation, and even foreign countries. Greater standardization and centralization of authority are inevitable features of such wider organization. Here, as elsewhere, local liberty and diversity yield ground before wider authority when improvements of communication and transportation have made wider contacts feasible, and when science, specialization, and integration have enabled a single worker with very special knowledge, records, and tools to function far more efficiently than could scattered, amateurish, and unequipped workers.

Not only in police preparatory work but also in court trial we may expect to see increased emphasis upon expert testimony, and a legal regularization of the position of the expert, perhaps giving him public and official rather than partisan status, and letting him determine conclusively the facts in his specialty. The spectacle of experts hired by opposing sides, arguing against each other in a courtroom, to win a decision from a jury and judge quite unacquainted with the chemistry, psychology, or other sciences they are arguing about, becomes anomalous, not to say distressing, in a scientific age.

Not only in identification but throughout police and penal methods and the opposing criminal ones we observe a rapid progress in the science available, and a lagging recourse to it.[45] The radio-receiving squad car can be equipped with a transmitter, as in several cities, for two-way short-wave communication, accurately crystal-tuned.[46] Indeed, a one-meter wave transmitter has been produced that transmits speech 4 miles, using less power than a flashlight, packed into a 3-inch cube,[47] and another set put in a hat, with a telescoping spike for antenna. It seems plausible that at least one policeman in every squad will be equipped both to send and receive by radiotelephone, so as to keep in constant touch with headquarters and with cooperating policemen, to work better and more safely.

In the fields of courts, law, and punishment we see few mechanical inventions, a number of social ones, and some progress in penological science. But there are strong legal and traditional obstacles to applying this science. The penologist's work is based upon principles of first directing youths away from crime, then treating the criminal, not punishing according to the crime; curing the curable and finishing off or imprisoning for life the incorrigible. But the penologist is not sure of his methods, nor is he allowed to experiment extensively. Some social inventions which he is permitted to use increasingly are the juvenile court, indeterminate sentence, socialized prison for segregated types and especially of late, the release of prisoners on supervised parole after scientific, socio-

[44] Quirke, A. J.: Forged, Anonymous, and Suspect Documents. Lon., 1930. Sandek, R.: Writing Movements as Indications of the Writer's Social Behavior; in Jour. of Soc. Psy., 2: 337–73.

[45] Improved burglar alarms are discussed in pt. three, ch. VII.

[46] Sci. Amer. 153: 77, August 1935.

[47] Pop. Sci. Mo., April 1936, p. 22, and January 1936.

logical study of their personal records and of the whole problem of predicting the probable success or failure of parolees.

There are growing scientific bases for attempting to understand the natures of individuals, to distinguish and measure to some extent the different types of character, intellect, and physique. Analysis is also going forward of the different jobs, responsibilities and domestic situations which different types of people are fitted to fill. New institutional means are further being devised for helping people to be placed most effectively. Formerly we depended largely upon courts, elections, and private employment agencies. Today, there have been developed juvenile courts, psychiatric bureaus for child, court, and obvious mental cases, and psychiatric and intelligence tests in schools, clinics, and prisons, classification of prisoners; parole boards handling indeterminate sentences with scientific prognostic methods; placement service for discharged convicts; supervised parole; vocational guidance; employment agencies on altruistic and public bases and civil service commissions and private personnel departments using intelligence, psychological and trade tests.

Against the sweep toward more public and private knowledge of the individual, there are, however, certain countervailing tendencies. Note has been made of the growths of population, urbanism and mobility. To a large degree the most intelligent criminals can thwart or twist the police sciences to their purposes, by avoiding leaving identifying traces, remodeling their faces, communicating by photophone perhaps, forging fingerprints, fooling the psychologist, corrupting file clerks, etc., especially with gang help. But the more science advances, diversifies into specialties, and establishes a closer knit police organization, the more helpless against the police becomes the single rebel or gang, and especially the ignorant criminal. They can all learn, but will probably not be able to keep pace with police science.

In fine, there have emerged many inventions opposing crime. But the army of disorganization has on its side important social forces we mentioned, of increases in mobility, urban population, crimes defined, and movable property, beside the abiding American traditions of libertarianism, local independence, and in some circles, admiration of crime.

The Areas of Government

Government, like other activities, feels the impact of technological changes. The drive toward organization and consolidation, which science and invention have brought in industry and economic life generally, results in problems of adjustment which concern all citizens. To enumerate the maladjustments which government has come to concern itself with and in the cause of which technological change has played an important role would require an extensive list in itself. Unemployment, industrial instability, agricultural distress, currency and banking, protection of labor, tariffs, crime, monopolies—these are all problems of vital concern to government—problems which the present machine age has brought to the fore.

While there has occurred steady growth of governmental functions in the last few decades at all levels of Government—Federal, State, and local—of particular note in light of technological developments is the recent trend toward consolidation and centralization. Some may view such tendencies with alarm. Almost every invention of transportation and communication, however, tends toward the enlargement of the areas of government. Such inventions are so numerous and important that more than one-third of the entire second part of this report is devoted to them. All inventions which make it possible for goods to be moved cheaper or more quickly, people to travel faster and more comfortably, or ideas to be better conveyed, in point-to-point or wholesale communication, tend, first, to build up larger, more widespread businesses. These tend to outrun the powers of local regulation and taxation and to become more and more subject to wider areas of governance.

At the same time businesses are thus enlarged, the desires of the purchasing public are being unified around national standards by communication, especially by national advertising and the movies, which spread over the whole nation desires for the same kinds of clothes, furniture, foods etc. Thus a large scale market is built up for national businesses with large-scale production. The unequalled productive efficiency and wealth of the American people can be traced mainly to their large-scale production of manufactures and excellent transportation and communication systems, accompanied by free trade and exchange among the 48 States.

At the same time that better transportation and communication are building wider business and mental uniformity, they are enabling governmental areas to grow wider to match them, by facilitating wider public business. By means of auto, telephone, and presently steep-flight aircraft, closer contact is coming between town and county seat, and between the many parts of a metropolitan area, often located in different States. Technological developments have brought such concentration into metropolitan areas that not only have increased services of government been called for, but also such services are depending more and more upon wider areas of administration for their efficient functioning. Similarly there arise closer links between all these areas and the state capital, by

faster trains and cheaper telegraphing and telephoning, and easier communication between all these and Washington by these means and by aviation, radio, and eventually television. All these inventions will help officials to confer with each other and with their staffs, experts to advise, every kind of distant business to be more easily handled, elected officers to be known to wider constituencies, and voters to be somewhat informed on and interested in broader issues.

Many shifts of power from smaller to larger units of government have been made by law, but many others are effected in more indirect fashion, by a transfer upward of interest, prestige, legislative, and administrative vigor and efficiency. Sometimes the inventional origin of a change is evident, as when the auto bus and better roads bring in the consolidated school and district, when the auto brings national road financing and need of wider police organization, when the superpower line and national holding company bring Federal regulation of electric power, and when the radio and airplane develop to require national and international regulation. More often than from single inventions, and indeed always in part, the change really comes largely because of the whole mass of thousands of transport and communication inventions which all go to encourage centralization of authority, even though among these only a few may be conspicuous.

One quiet force making for wider areas of control is the need of a wider source for taxation. So long as the country's wealth was mostly in real estate, especially agricultural land, the general property tax and local administration of it sufficed very well for most purposes. But new inventions in agriculture and industry have helped cut the farm population to a quarter of the whole, and communication and transport progress have gathered much of the Nation's wealth into the hands of great national corporations, of which 200 are said to control 38 percent of the business wealth of the country, according to Berle and Means. The ownership of the corporations is scattered among people who live mostly in the metropolitan centers, far from their industrial properties, and who can be taxed most effectively only through the national income tax. Hence the growing inability of the small, local governments to bear their burdens of education, relief, etc., and a disposition to support and administer such services from the State and National capitals.

Just as the improvements of communication and transportation all tend to involve the different regions of the country more with one another, and therefore to build up the central, national authority as the only possible harmonizer of conflicting interests, so the same inventions, but especially those for transoceanic freight, passenger, and ideal traffic, tend strongly to build up international cooperation and organization. Take such problems as international postal and telegraph services, the repartition of radio wave lengths, the repression of the illicit drug traffic, the protection of labor, the establishment of international languages such as the marine signal code and the scientific terminologies, calendar reform, the business of the many world conferences occurring each year and drawing up international agreements, and any encouragement of world peace—such problems can be solved only internationally. The world-spread culture gives a basis for mutual understanding, and whether the League of Nations be followed or not, there result inevitably international conventions and common action, involving every important country. This means that we follow not simply our own will, but more that of the consensus of the nations; whence national government is, in some small degree, superseded by international organization.

On the other hand, increasing contacts in some ways bring new frictions, as through radio propaganda, and the fear of airplane raids. In such ways international disorganization is promoted; but probably the uniting effect is the greater. While invention modifies political practices, in turn political principles modify what will be done with inventions. For illustration, when the first railway cars were being built in America, far from making them identical or at least interconnectible, some little roads even deliberately adopted a different rail gage, to prevent all possibility of through movement of cars. Much later rival single-track roads were built side by side for great distances. Unity would always have been technically desirable, and was enforced in Europe, but in America the political philosophy of that age saw more advantage in free competition. The standardized, interconnectible, and life-saving Janney car coupler was not insisted on until the beginning of the century. But when, at later epochs, the airplane and radio came along, national and even international standardization and control were enforced early, not because the needs of these devices were essentially very different from those of the railroads, but because the political philosophy had changed, and no strong vested interests nor established customs stood in the way.

Every page of this chapter has been pointing out inventions of significance to government, i. e., forthcoming technological developments in which the federal or a minor government might probably, if it wished to, accomplish some progress or ward off some impending evil by taking some sort of legislative or administrative action with reference to the new invention. As examples, there have been pointed out

the immense political power of television, the opportunity for machines in education, and the tendencies for noise to increase. References have been on the basis of the political principles usual today; according to those of the 1880's, such matters were no concern of government.

Examples of how, under modern conditions, invention may invite governmental action are found in the case of all sorts of materials for consumers' goods. Technological improvements introduce vast numbers of new products, notably chemical products and foods. The consumer is confused by the multiplicity of the substances which he has no way of distinguishing. Trade names add to his confusion. Acetate rayon, for example, commonly bearing some trade name, needs quite different treatment in cleaning and dyeing from ordinary cellulose rayon and from all natural fibers. One plastic may be heated with impunity, while another would soften or catch fire. The need that people generally shall know how the materials which they have bought can be protected, cleaned, resurfaced, repaired, altered, and finally salvaged or used for scrap, may call for action by Government or trade associations, for proper labeling, as already in the case of drugs.

Broadly considered, the drive toward integration which has accompanied technological developments has meant that the activities of government have come to concern themselves more and more with situations and organizations, rather than with individuals as such. In past decades, many a person was killed by horse traffic. But with horses and vehicles unstandardized and so fully in the control of individuals and small dealers, the Government made little attempt to regulate them, almost wholly confining itself to ordaining that whoever did injury by reckless driving should pay damages or be punished. Today, with nearly all the autos in the country being built by a dozen companies, they seem more "get-at-able", and governments try to prevent accidents before they happen, by requiring brakes and lights up to certain standards, and establishing traffic signals and rules, and police to command each move where the traffic is thickest. Today we are inclined to regulate situations and group units, by many special laws. Formerly we punished people after the wrong was done, by general laws, on the theory that they chose to be reckless or malicious, and that their punishment would deter others in the future. When every American family made its own light from tallow, pitch pine, or what they could find, State regulation of the light business would have been absurd. But when the lights in a city are dependent upon one generating station and one company, regulation becomes feasible and desirable. The growing interdependence of economic life with its high degree of organization, and the fact that now almost every vital concern of life is at some stage on a wholesale basis, make it both easier and often needful to regulate the large-scale stage, rather than to attempt to pick out and punish some individual wrongdoer after the harm is done.

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IV. RESISTANCES TO THE ADOPTION OF TECHNOLOGICAL INNOVATIONS

By Bernhard J. Stern [1]

Introduction

Prognoses can be made as to inventions in the offing through a knowledge of the cumulative developments and lines of research in specific fields of technology. But such predictions are unrealistic unless they take into consideration the social and economic setting of these innovations. Basic inventions may be still-born and entire lines of potential development be prevented, not because of deficiency in engineering plans, but because of factors entirely beyond their scope. Predictions based upon the assumption that if valuable or profitable technological inventions are but conceived, they will be incorporated into industrial life, ignore the evidence of past experience. For the history of inventions in technology is replete with frustrations and protracted delays in the acceptance of innovations which subsequently have proven of inestimable value to mankind.

The acceptance or rejection of technological innovations depends to a large measure on whether they are introduced at a time when an economy is static, contracting or expanding; whether they appear in a setting of social stratification, of anarchic competition and class struggle, or in a planned industrial order. Within these varied frameworks there are other psychological and cultural factors that determine receptivity to technological innovation which can be brought into perspective by a study of specific cases of opposition to technological change.

The purpose of this report is twofold. It is to present evidence through historical, analytical inquiry that resistance to technological innovation is frequent and powerful enough that it must be taken into consideration when discussing trends, and it is to investigate the socio-economic and psychological factors which are involved in this resistance.

1. Resistances to Technological Innovations in Various Fields

There will be no attempt here to make an exhaustive compilation of all cases where technological change has met resistance. The high frequency of such opposition makes selection imperative. The basis of choice has been not the spectacular, but the normal occurrence of resistance to technological innovations, throughout history, but particularly in recent western societies, in fields which most influence man's life and livelihood, and permit his control and effective utilization of his natural environment. The number of cases discussed will be sufficiently diverse and adequate to give insight into the causes of such resistance and to permit generalizations that have wider applicability.

Transportation

It is clearly to man's advantage to be able to traverse distances with facility and in ease, yet innovations permitting more comfortable and more rapid mobility generally have encountered apathy or overt resistance, and their utilization has repeatedly been restricted by vested interests. In the thirteenth century such resistance manifested itself in the case of the use of carriages. Philip the Fair ordered the wives of citizens of Paris not to ride in carriages in order to preserve the prerogatives of the ladies of the court.[2] A law likewise sought to prevent the use of coaches in Hungary in 1523, and the Duke Julius of Brunswick in 1588 made riding in coaches by his vassals a crime punishable as a felony, largely on the grounds that it would interfere with military preparedness, for men would lose their equestrian skill. Philip II, Duke of Pomerania-Stettin, also commanded his vassals in 1608 that they should use horses and not carriages.[3] In England, coaches were not widely used until the time of Elizabeth, who rode only reluctantly in this effeminate conveyance which young men scorned.[4] In Donegal, Ireland, as late as 1821, carts to carry produce, which had previously been carried in creels on ponies' backs, were rejected as useless.[5]

There were many impediments placed in the way of stagecoaches in all countries. Local authorities often kept the roads in disrepair lest business be diverted elsewhere. Strangers were taxed excessively for horses, repairs, and stoppages. Tolls and passport requirements were onerous. Even at the beginning of the nineteenth century one traveling from Gottingen to Rome had to have his passport vised about 20 times.[6] Such political interference involved delays

[1] Department of Social Science, Columbia University.

[2] Yeats, John, The Technical History of Commerce (London 1872), p. 178.

[3] Beckman, Johann, Beyträge zur Geschichte der Erfindungen. 2 vols. (Leipzic 1783–1805) tr. by William Johnston as A History of Inventions, Discoveries, and Origins. 2 vols. (4th ed. by William Francis and J. W. Griffith (London, 1846), pp. 72–73.)

[4] Bishop, J. L., A History of American Manufactures From 1608 to 1860. 3 vols. (3d ed., Philadelphia, 1868) vol. i, p. 20.

[5] Hamilton, John, Sixty Years' Experience as an Irish Landlord, ed. by H. C. White (London, 1894), pp. 47–48.

[6] Boehn, Max von, and Fischel, Oskar, Die Mode; Menschen und Moden in neunzehnten Jahrhundert. 4 vols. (Munich, 1907–19) tr. by Marian Edwardes as Modes and Manners of the Nineteenth Century. 4 vols. (Rev. ed., London, 1927) vol. i, pp. 177–178.

and expense, and discouraged travel by stagecoaches long after they were well equipped for distance travel.

Railroads.—Turnpike companies profiting by tolls, and owners of stagecoaches were among the most active opponents of railroads. They were supported by tavernkeepers along the route of the roads, and by farmers who felt that the introduction of the railroad would deprive them of markets for horses and for hay. In the United States, Congress had initiated an extensive program of road-building and had already built a national road and many post roads that facilitated travel. The argument that a system of macadamized public highways would better serve the Nation than railways deserved serious consideration when the dispersion of the population and the crudeness of early railroad development is considered. At this time, also, steam carriages were being considered as a commercial possibility to supersede horses in propelling stagecoaches, and the conflict therefore was not merely between slow railroads and fast horses, which often beat the trains on good roads, but rival forms of steam conveyance, one confined to fixed routes on the rails, the other more mobile. The current competition between the railroads and autobuses was thus anticipated. The railroads emerged as victors in such a decisive fashion that extensive roadbuilding and the development of mechanical conveyances on these roads were checked for decades.

Advocacy of the "people's road" as against monopolistic railroads became one of the political issues of the Jacksonian period. It was argued in Congress that railways were "vastly inferior" to roads and that "Democratic-Republicans" wanted a road on which all could travel together "no toll, no monopoly, nothing exclusive—a real 'people's road.'" [7] This opposition was engendered not merely by the fact that the railways business required a considerable capital and a corporate form that made it a "moneyed power", but also by the fact that the railroad operators could hardly have been said to have represented the people's interest, or to have acted in a manner to elicit public confidence. Speculative financing which ruined small investors, the many fraudulent construction contracts, the sale of stock on "through-lines" which remained only branches, the wasteful wars between competing companies, the "squeezing out" of minority stockholders, the high stipends of the railroad directors, the land grabs and excessive subsidies obtained through the bribery of corrupt legislators, and other sharp dealings roused public sentiment against the railroad interests and stimulated hostility to their projects.

In England the resistance to the railroad was largely from the landlord class which, with its feudal privileges, arrayed itself against the aggressive industrial bourgeoisie. The temper of the opposition is to be seen in the remarks of Craven Fitzhardinge Berkeley, a member of Parliament for Cheltenham: "Nothing is more distasteful to me than to hear the echo of our hills reverberating with the noise of hissing railroad engines running through the heart of our hunting country, and destroying that noble sport [fox hunting] to which I have been accustomed from my childhood." Sir Astley Cooper, the eminent surgeon, is quoted as saying to Stevenson: "You are proposing to cut up our estates in all directions for the purpose of making an unnecessary road. Do you think for one moment of the destruction of property involved in it? Why, gentlemen, if this sort of thing is allowed to go on, you will in a very few years destroy the noblesse!" [8] It was in protest against the mounting spirit of industrialism that Ruskin, rejecting the "nonsensical" railroad, drove through England in a mail coach.[9]

In the United States likewise there was opposition to the railroad in a similar strain. It was argued that its use would: "introduce manufactures into the heart of the country, divert industry from the primitive healthful and moral pursuits of agriculture, and bring on us the vices and miseries of manufacturing and commercial places." [10] Many small towns joined the opposition, some on the grounds that their quiet would be interrupted by steam cars and the influx of strangers, others because business would be diverted to the larger cities. Stephen Van Rensselaer, for example, who was originally one of the wealthy backers of a charter for a railroad between Albany and New York, later opposed the plan on the ground that Albany would be ruined because the railway would divert travel and traffic to Manhattan.[11]

The vested interests of canal owners, and the sentiments of legislators committed to the building of public canals in which there were already considerable investments, were arrayed against the railroads. Surveyors laying out the road for the Liverpool and Manchester Railway were threatened with violence by the manager of canal properties on the estate of the Duke of Bridgewater and by Lords Derby and

[7] Haney, L. H., A Congressional History of Railways in the United States to 1850, in University of Wisconsin Bulletin, Economics and Political Science Series, vol. III (Madison, 1908), pp. 167–438, 247–248.

[8] Quoted in Burgess, E. W., The Function of Socialization in Social Evolution (Chicago, 1916), pp. 18–19.

[9] Ludwig, Emil, In Defense of Our Machine Age, in New York Times Magazine (Oct. 21, 1928), pp. 1–2, 23.

[10] Haddock, Charles B., An Address Delivered before the Railroad Convention at Montpelier, Vt. (Montpelier, 1844), pp. 10–14. Quoted in Corey, Lewis, House of Morgan (New York, 1930), p. 25.

[11] Lant, A. C., The Romance of the Rails. 2 vols. (New York, 1929), vol. I, p. 17.

Sefton, and farmers were incited against them.[12] Aided by the landed gentry and the turnpike owners, the canal companies campaigned so vigorously against the railroad that the expenditure of £27,000 was required by the railroad interests to win Parliamentary approval.[13]

In the United States when, in 1812, John Stevens wrote his Documents Tending to Prove the Superior Advantages of Railways and Steam-carriages over Canal Navigation addressed to the commissioners appointed by the State of New York to explore a route for the Erie Canal, his proposals were regarded as ingenious but visionary, and dismissed in the face of the recommendation for the canal by DeWitt Clinton, Gouverneur Morris, and Robert R. Livingston. The latter, Steven's brother-in-law, had been granted a monopoly to navigate the waters of New York State by steamboat and could, therefore, not be expected to be receptive. His letter, dated March 11, 1812, gives the reaction of an "expert" of the time:

> ALBANY, *11th March 1812.*
>
> * * * I had before heard your very ingenious propositions as to the railway communication. I fear, however, on mature reflection, that they will be liable to serious objections, and ultimately more expensive than a canal. They must be double, so as to prevent the danger of two such heavy bodies meeting. The walls on which they are placed must at least be four feet below the surface, and three above, and must be clamped with iron, and even then would hardly sustain so heavy a weight as you propose moving at the rate of four miles an hour on wheels. As to wood, it would not last a week; they must be covered with iron, and that, too, very thick and strong. The means of stopping these heavy carriages without a great shock, and of preventing them from running upon each other (for there would be many on the road at once) would be very difficult. In case of accidental stops, or the necessary stops to take wood and water, etc. many accidents would happen. The carriage of condensed water would be very troublesome. Upon the whole, I fear the expense would be much greater than that of canals, without being so convenient.[14]

When later in 1815 in New Jersey, and in 1823 in Pennsylvania, Stevens received a charter for railroads, capitalists could not be sufficiently convinced of the efficacy of his proposals to give him adequate funds.[15]

After New York had incurred a heavy debt in the construction of the Erie Canal, mass meetings throughout the State demanded that railroad competition should not be permitted to affect the receipts of the canal. When the charter of the Utica and Schenectady Railroad was granted in 1833, the line was prohibited from carrying any property except the baggage of passengers, a prohibition which prevailed until 1844, when permission to carry freight was granted but only when navigation was suspended and upon the payment of canal tolls. The general railroad incorporation act of 1848 levied canal tolls from railroads parallel to canals and within 30 miles, and not until 1851 were restrictions of this character removed. In Pennsylvania also, where there were many State canals, popular sentiment was strong against railroad competition and tonnage taxes were imposed on the Pennsylvania Railroad that were not lifted until 1861.[16]

Propaganda of vested interest groups was potent. It was easy to arouse opposition of farmers along the right-of-way, on the grounds that the roaring locomotives would startle the cattle and prevent them from grazing in safety, that hens would not lay, that the poisoned air from the locomotives would kill the wild birds and destroy vegetation, that farmhouses would be ignited by sparks, and property would deteriorate. Farmers likewise were made apprehensive lest through competition there would be no market for horses, and that their crops of oats and hay would be valueless.[17] But the propaganda did not stop with such arguments. An eloquent divine in the United States went so far as to declare that the introduction of the railroad would require the building of many insane asylums, as people would be driven mad with terror at the sight of locomotives rushing across the country with nothing to draw them. Railroads were likewise denounced as impious because they were not foreseen in the Bible.[18]

The railroad deviated from its predecessors slowly. Before steam power was used on the railroads, horse-drawn cars were employed as well as horsepower treadmill cars. First, wooden, and then short-lived and expensive cast-iron rails were used for the horse-drawn railroad coaches that differed so little from the stage coaches that they were sometimes equipped with arm straps to ease the jolts of the journey. In 1829 a horse treadmill car carrying 24 passengers was given a price of $500 by the Charleston and Hamburg Railroad. Cars equipped with a mast and sail were tried

[12] Smiles, Samuel, The Life of George Stephenson (Boston, 1858), pp. 197–202.

[13] Kaempffert, Waldemar, When the Locomotive Was a Mad Idea, in New York Times Magazine (Oct. 6, 1929), pp. 4–5, 20.

[14] Stevens, John, Documents Tending to Prove the Superior Advantages of Railways and Steam-carriages Over Canal Navigation (New York, 1812), p. 21.

[15] Mitman, C. W., The Beginning of the Mechanical Transport Era in America, in Smithsonian Inst. Ann. Rept., 1929 (Washington 1930), pp. 507–558.

[16] Cleveland, F. A., and Powell, F. W., Railroad Promotion and Capitalization in the United States (New York, 1909), pp. 73–75.

[17] Francis, John, A History of the English Railway, 2 vols. (London, 1851), vol. i, pp. 101–102, 107–108.

[18] Laut, op. cit. vol. i, pp. 12–13.

by two railroads that would not commit themselves to steam until the success of George Stephenson's "Rocket" in England in 1829 removed most doubts.[19]

The early inventors of steam-drawn vehicles had all been discouraged (see p. 43). Stephenson, too, had had his difficulties. In 1814 he had developed an engine for a coal tramway that drew 8 loaded wagons weighing 30 tons at 4 miles an hour. Yet 7 years later, when he became engineer for the Stockton and Darlington line, the projectors of the company were so doubtful of steam transportation that the act which they had passed by Parliament specified only that the haul should be "with men and horses or otherwise."[20] The indifference and resistance to steam for transportation provoked Oliver Evans to indignant observation: "When we reflect upon the obstinate opposition that has been made by a great majority at every step toward improvement; from bad roads to turnpikes, from turnpike to canal, from canal to railways for horse carriages, it is too much to expect the monstrous leap from bad roads to railways for steam carriages at once. One step in a generation is all we can hope for. If the present shall adopt canals, the next may try the railways with horses, and the third generation use the steam carriage."[21]

Disparagement of the efficiency and potentialities of the steam railroad flourished on fertile soil. Passengers were frightened by the danger that boilers would burst, as they sometimes did. Some asserted that locomotives would never be a success because their weight prevented them from attaining speed. It was frequently argued that mud and dust in summer and snow in winter would render a railroad impractical. Daniel Webster, for example, doubted its ultimate success, arguing that frost on the rails would prevent a train from moving, or if it did move, from being stopped. No reputable engineer would appear before the British Parliamentary Committee to testify in favor of steam locomotives, and Stephenson's request for a charter was at first refused. The early locomotives could in fact run only on almost level ground; they lacked much power and were expensive.[22]

In 1826 an engineer, quoted with approval in Amroyd's work on internal navigation, declared "a rate of speed of more than 6 miles an hour would exceed the bounds set by prudence, though some of the sanguine advocates of railways extend this limit to 9 miles an hour."[23] John Steven's prediction of the possibilities of 20 miles an hour or more was satirized in a newspaper in a manner that reveals latent fears:

> Twenty miles an hour, sir! Why you will not be able to keep an apprentice boy at his work! Every Saturday evening he must have a trip to Ohio to spend a Sunday with his sweetheart. It will encourage flightiness of intellect. All conceptions will be exaggerated by the magnificent notions of distance. Only a hundred miles off! Tut, nonsense, I'll step across, madam, and bring you your fan.[24]

In England, Nicholas Wood, whose position was that of "railway expert" declared Stephenson's claim of a possible speed of 20 miles an hour absurd and added "Nobody could do more harm to the prospects of building or generally improving such coaches than by spreading abroad this kind of nonsense." In Germany, it was proven by experts that if trains went at the frightful speed of 15 miles an hour on the proposed Rothschild railroads, blood would spurt from the travelers' noses, mouths, and ears, and also that the passengers would suffocate going through tunnels.[25] As late as 1834 the average rate of speed of railroads was not much greater than that attained by horses on good roads, so that mail contracts were sometimes awarded to stages for making better time.[26] Almost universally there was a stress on hazards and imperfections, and a failure to conceive of the potentialities of the railways. It was not until 1860 in Germany, for example, that the use of railways for the transport of troops in case of war was considered.[27] The derogatory attitude toward the steam locomotives is reflected in the bantering designations given them, such as "hell on wheels", "puffing John Bulls", "devil wagons", "black dragons", "snorting race horses." The commercial profit-making drive of the railroad builders did much to augment the revulsion of the agricultural groups to this symbol of industrialism, for they were not concerned with remedying its ugliness, smoke, and grime. Aesthetic considerations were considered outside of their province. When a famous artist volunteered to paint a mural in a railway terminal in London his offer was refused on the ground that art had nothing to do with machinery.

Each improvement in railroad equipment and organization has been marked by opposition and delay especially when it involved costly equipment rendering the older stock obsolete. Commodore Vanderbilt dismissed Westinghouse and his new air brakes with the remark that he had no time to waste on fools.[28] When W. R. Sykes in 1874 presented plans for a system of

[19] Mitman, op. cit. p. 536.
[20] Smiles, op. cit. pp. 92, 159.
[21] Mitman, op. cit. p. 529.
[22] Haney, op. cit. pp. 200–201; Cleveland and Powell, op. cit. pp. 46–66.
[23] Crozet, C. in George Amroyd. A Connected View of the Whole Internal Navigation of the United States (Philadelphia, 1830), p. 570.
[24] Mitman, op. cit. p. 534.
[25] Corti, E. C., Das Haus Rothschild in der Zeit seiner Blute, 1830–1871 (Leipzic, 1928) tr. by Brian and Beatrix Lunn as The Reign of the House of Rothschild (New York, 1928), p. 77, 94.
[26] Haney, op. cit. pp. 237–238.
[27] Bochn and Fischel, op. cit. vol. iii, p. 129.
[28] Hart, Hornell, The Technique of Social Progress (New York, 1931), p. 631.

automatic signalling on British railroads, the board of trade and the directorate of the railway companies maintained that personal care by signalmen was much better than any automatic system.[29] It was charged in 1912, before a Senate committee that a railroad company had taken out patents on safety devices and had refused to manufacture them.[30] It took Janney 10 years before he could get a founder to manufacture his car-coupler.[31] The design of Pullman sleepers in the United States has remained relatively static since it was first built in 1859.

The wide use of electric locomotives has been delayed because of capital loss on old equipment, and the belief that the costs of electrification and new equipment are not justified by the volume of traffic. Railroad companies vigorously opposed the legislation requiring their installation on trains entering the limits of New York City through tunnels. Streamlined trains were tried on the continent as far back as the nineties, and in 1900 the Baltimore and Ohio ran one that made 82 miles an hour on open road with a six-car train.[32] But the cost of replacing the old engines and the rolling stock, and the need for improvement of road beds, have delayed their extensive introduction.

Recent attempts to coordinate railway terminal facilities have been marked by strenuous opposition from many of the directors of large railroad systems because such coordination threatens to disrupt the hold they have on freight traffic in many of the important centers of the country, and by the railroad brotherhoods who seek protection for railroad workers, who will be displaced.

The railroad interests are now in the position that the turnpike and canal interests were at the beginning of railroad history. As entrenched groups having difficulty to compete because of the costs of modernizing their obsolete equipment, they are combating the increasing competition of auto trucking and bus transportation by devious obstructions—legislative and otherwise. They are likewise arrayed in opposition through lobbies and through widespread propaganda against the extension of waterways.

Automobile.—There were many precursors of the modern automobile that failed to survive the opposition and apathy of their times. A three-wheeled carriage driven by two steam cylinders was invented by Joseph Cugnot in 1769 which actually moved a load in addition to its own weight, but it did not succeed in capturing popular support. In England when William Murdock built a one-cylinder steam-driven vehicle about 1784, Watt, his employer, who opposed the use of steam engines for road transportation, discouraged him. Maryland in 1787 granted Oliver Evans rights for a steam wagon with the comment that "it would doubtless do no good, but certainly could do no harm", and later his project was called chimerical. Sir Goldsworthy Gurney's steam coach made regular trips between Cheltenham and Gloucester in the 1820's, and although it was financially successful, it was abandoned because of the opposition of the landowners, stagecoach proprietors, and the breeders and users of horses. All animal lovers were marshaled in defense of the horse by vested-interest groups, and the steam coach was denounced as dangerous to the health of the community because of the smoke, steam, and hot ashes it left in the streets.

In the 1860's it appeared that mechanical transportation had come to stay in England, but again the opposition of horse breeders and railroads stood in the way. They secured passage of an act of Parliament, in 1861, for the regulation of horseless vehicles which practically made it impossible for them to operate. This act provided that tires must be at least 3 inches wide, that engines must consume their own smoke, that each vehicle must have at least two drivers, and that no vehicle was to exceed 10 miles an hour in the country and 5 miles an hour in the towns. In 1865 an even more drastic act was passed requiring three drivers for each vehicle, one of whom must precede the carriage at a distance of 60 yards, carrying a red flag by day and a red lantern by night. Speed was reduced to 4 miles an hour for the country and 2 miles an hour for the towns, and local communities were given the right to tax the operation of vehicles and to prescribe hours of operation which they did in a discriminatory manner. With such restrictions, which were not repealed until 1896, the steam carriage was doomed.[33] In the United States, George Brayton fitted a gasoline engine to a Providence streetcar in 1873, and another to a Pittsburgh omnibus in 1878, but both were denied the streets.[34]

The automobile propelled by the internal-combustion engine made its way slowly against ignorance, apathy, and competition. In 1890 and 1891 the Chicago World's Fair advertised universally for exhibits in "steam, electric, and other road vehicles propelled by other than animal power", but made no specific mention of the internal-combustion engine. One of the greatest sales obstacles the gasoline car had to overcome was the widespread conviction that Edison would invent a superior and cheaper electric automobile. As

[29] Hatfield, H. S., The Inventor and His World (London, 1933), p. 105.

[30] U. S. Congress, Senate, Committee on Patents, Revision of Statutes Relating to Patents: Hearings. 67th Cong., 2d Sess. (1922), p. 205.

[31] Mitman, op. cit. p. 545.

[32] Leonard, J. N., Tools of Tomorrow, New York, 1935, pp. 205–206.

[33] Hunt, F. B., Self-Propelled Cars Sought 500 Years Ago, in New York Times, Apr. 27, 1930, p. 11.

[34] Duryea, C. E., "It Doesn't Pay to Pioneer", in Saturday Evening Post, vol. ccili (1931), pp. 30, 98, 102.

late as 1896, A. R. Sennett read a paper before the British Association for the Advancement of Science in which he maintained that the steam engine rather than the internal-combustion engine would prevail and that petroleum propulsion had to improve a great deal before heavy loads could be dealt with or passengers conveyed "free from excessive vibration and offensive exhalations and with a degree of luxury at all comparable with that which we have come to identify with horse-drawn vehicles." He likewise contended that horseless carriages could not be widely used because they required great skill, inasmuch as the driver "has not the advantage of the intelligence of the horse in shaping his path."[35] In a communication to the city council in 1908, the mayor of Cincinnati declared that the driving of an automobile requires such qualifications that no woman is physically fit to undertake the task.

Automobiles did not develop beyond an embryonic stage for many years and their possibilities were not envisioned. The first cars were really only horse carriages with crude power plants. It was not until 1909 that left-hand drive and center control were introduced. The first Packard car body delivered to the manufacturers had a whipstock on the dash-board. Breakdowns were frequent. Repairs were distressingly difficult and expensive. Parts were not standardized and not easy to get. The automobile came to be known as the "rich man's toy", and there was no conception of it as a reliable and indispensable means of transportation. As late as 1902, when President Theodore Roosevelt rode in an automobile it was followed by a horse-drawn carriage in case of an accident. Not until 1909 did production figures of passenger cars pass the 100,000 mark, and the production of motor trucks did not reach 10,000 until 1911.[36]

The attitude toward the automobile was more than apathetic; it was scornful. In 1895 Samuel Bowles II, the editor of the Springfield Republican, refused an invitation to ride in the car with which Duryea had won the first American automobile race, on the grounds that it was incompatible with the dignity of his position.[37] Lord Montague vividly describes the prevalent hostile attitudes toward the early motorists: "Among our friends we were considered mad. In the press we were held up to public derision, sometimes as fools, sometimes as knaves; and every accident that happened, even remotely connected with the motor car, was attributed to the 'new Juggernaut' as it was called. The papers were almost without exception hostile."[38]

The task of changing popular attitudes was a paramount one before automobiles could be sold. Slogans such as "Get a Horse" and "Down with Road Hogs" had to be replaced by "Goodbye Horse" and "Nothing to Watch but the Road." Songs like "Get Out and Get Under" were counteracted by "My Merry Oldsmobile." Active propaganda was necessary to combat the influence of clergymen, who flayed "automobilitis" as deleterious to morals and religion. European monarchs delayed long before they admitted that an automobile was dignified enough for them. Emperor Francis Joseph I of Austria, who died in 1916, for example never entered an automobile. Horse-drawn carriages are still used in royal processions, and they likewise are utilized widely for funerals in all countries.

Financiers were in nowise ahead of popular sentiment in reference to the automobile. They had no conception of its future development, and looked askance upon it. Both R. E. Olds and Charles E. Duryea testify as to the hostile reception they received in Wall Street where the bankers could not see the wisdom of investing a few thousand dollars in what they considered a plaything. Chauncey M. Depew confessed that he warned his nephew not to invest $5,000 in Ford stocks because "nothing has come along to beat the horse." W. C. Durant's prediction that some day 500,000 automobiles would be manufactured annually in the United States is said to have provoked George W. Perkins to declare "If he has any sense, he'll keep those notions to himself if he ever tries to borrow money." J. P. Morgan & Co. refused to buy for $5,000,000 in 1908 a block of securities which were later incorporated in General Motors and rose to a value of $200,000,000.[39] The financiers exaggerated the numerous mechanical imperfections that existed in the early cars, stressed the absence of good roads, were deterred by litigations over the early patents, and above all could not envisage a profitable market.

Changes in the automobile that would increase its sales possibilities by making its use simpler and its power greater were accepted slowly. The self-starter was invented in 1899, and installed on one brand of car in 1902. It was impossible, however, to get manufacturers to spend money on "refinements", and by 1912 less than 5 percent of the manufacturers were offering cars with self-starters as standard equipment.[40]

French auto manufacturers perfected a V-shaped eight-cylinder motor several years before American manufacturers showed the feasibility of producing an eight-cylinder car in quantity. In 1914, such a car was

[35] Quoted in Robbins, L. H., "Old Cry 'Get a Horse' Echoed in the Sky", in New York Times Magazine, Dec. 23, 1928, pp. 4, 13.

[36] Automobile Manufacturers Association, Automobile Facts and Figures (New York, 1935), p. 4.

[37] Duryea, op. cit., p. 102.

[38] Robbins, op. cit., p. 4.

[39] MacManus, T. F., and Beasley, Norman, Men, Money, and Motors (New York, 1929), pp. 5, 113, 117.

[40] Epstein, R. C., The Automobile Industry (Chicago, 1928), pp. 105–107, 110.

produced, yet by 1926, production still consisted of 64 percent fours, 34 percent sixes and 2 percent eights. It was not until 1932 that Ford—who had likewise delayed adopting the standard selective three-speed transmission until December 1927—deserted the four-cylinder types to manufacture eights. By 1934, when fours practically ceased being manufactured, eight-cylinder cars still comprised only 40 percent of production.[41] A large portion of British automobiles were equipped with four-wheel brakes in 1923, when only 3 percent of American cars were so equipped; it was not until 1927 that as many as 90 percent had four-wheel brakes as standard equipment.[42] It required 7 years for the superior balloon tire to lead over the high-pressure tire. The large difference in costs between the closed car and the open car caused the manufacture of open cars to exceed closed until 1925; by 1935 the open car had practically disappeared.[43] The problem of disturbing the market, through depreciation of price of products, and the rigidity of large-scale enterprise, have been potent factors in delaying acceptance of innovations in automobile production.

The delay in the development of interurban bus transportation due to the competition of railroads has already been mentioned. The equally intense and discriminatory competition against busses by streetcar companies possessing "perpetual" franchises delayed the development of auto-bus transportation for decades.

Streetcars.—The history of streetcar transportation was likewise marked by insistent opposition in all its phases. The franchise granted the New York and Harlem Railroad in 1831, authorized tracks only in what was then an outlying district of New York City and even these were to be removed if they proved to be an impediment. Wealthy citizens successfully opposed the extension of the tracks southward for many years. A. T. Stewart, the department-store owner, spent over a half million dollars in a quarter-of-a-century fight against replacing the old stages with more modern horse cars, on the grounds that the streetcars would keep his fashionable patrons from driving their carriages to his store.[44]

When in 1858–59 George Francis Train got permission to lay tracks for streetcars in Great Britain, his plans had to be abandoned as unsuccessful largely because the rails projected above the surface of the highway obstructing other vehicular traffic.[45]

Horse car lines continued to be installed in the 1880's in New York City after cable cars had proven successful in San Francisco and they persisted in use until the 1900's. Strenuous opposition of civic and municipal authorities to posts planted in streets and wires across highways for overhead conductors delayed the introduction of electric trolley lines. Cincinnati, which began with a two-trolley overhead system, has continued it.

The decision of the Appellate Division, First Department of the New York Courts in 1896, which refused to approve the building of a subway, began with a quotation from St. Luke and continued: "The probabilities indicate that after sinking $51,000,000 in it (the subway) without being able to complete it, the enterprise would have to be abandoned * * * All that beheld it would begin to mock, saying 'this city began to build and was not able to finish'."[46] Property owners prevented the first subway from being dug along the most desirable routes. Plans for building a subway in Chicago have never been realized, although they have repeatedly been considered. The costs of obsolescence and the vested rights of franchise have prevented urban transportation from keeping abreast of technological changes.

Marine Transportation.—Gilfillan, who has made a sociological study of the invention of the ship, declares in reference to resistance to change in marine transportation:

> The jib and other fore-and-aft sails, the rudder, steamboat, screw, high pressure, surface condensation, compound and triple expansion, improved rudders and rotorship have had to fight their way. Only the compensated compass do we recall as meeting what might be called an immediate acceptance.[47]

There is especially well-documented evidence on the opposition to the use of steamboats. John Fitch was reviled and harassed as a deranged and suspicious character. In his memoirs he tells of his reception when in 1787 he appealed for financial support:

> [I was treated] more like a slave than a freeman. * * * Not only that; I have been continually seized with duns from our workmen, and imbarassed with Constables, for debts; and I was of so bare and mean an appearance that every decent man must and ought to dispize me from my appearance. Not only that, but dare not scarsely show my face in my own Lodgings; * * * [I] was obliged to suffer just indignities from my landlord and be henpecked by the women. Added to this, there was the Most Powerful combination against me, who thought that they could not serve God or themselves better than by saying every ill natured thing they could of me.[48]

[41] Automotive Industries (Feb. 22, 1936), p. 239.

[42] Epstein, op. cit., p. 110–115.

[43] Automobile Manufacturers Association, Automobile Facts and Figures (New York, 1935), p. 11.

[44] Lynch, D. T., "Boss" Tweed (New York, 1927), p. 80.

[45] Talbot, Frederick A., All About Inventions and Discoveries (New York, 1916), p. 87.

[46] Quoted in Sullivan, Mark, Our Times, 6 vols. (New York, 1926–35), vol. i, pp. 515–516.

[47] Gilfillan, S. C., The Sociology of Invention (Chicago, 1935), p. 106.

[48] Quoted in Boyd, Thomas, Poor John Fitch (New York, 1935), pp. 213–214.

The Pennsylvania Assembly, which had at that time subsidized Whitehead Humphries' experiments with a steel furnace, refused a year's loan to Fitch by a vote of 32 to 28. To raise money which he urgently needed, Fitch wrote to Benjamin Franklin as head of the American Philosophical Society, offering to sell to the society for a nominal sum, a model of the steam engine which Franklin had suggested should be made. The latter never responded and the society took no action. In 1790, when Fitch's steamboat was making technically successful trips on the Delaware River, with its schedule of daily sailings advertised in the Philadelphia daily newspapers, Benjamin Franklin Bache, the philosopher's grandson, ridiculed the boat as follows:

> A boat on this construction, barring all accidents of breaking paddles, cranks, gudgeons, watchwheels, chains, Loggerheads, cocks, valves, condensers, pins, bolts, pistons, cylinders, boilers, and God only knows how many more useful parts, would almost stem the tide of the Delaware * * *[49]

The chief difficulty was in drawing passengers away from the shallops and the stagecoaches; lures of beer, sausages, rum, comfortable cabins, and faster trips did not succeed in doing so.

"The God of Fortune was a Blind whimsical Jade!", Fitch once wrote, "Here she got Job cannonized for a Saint while I must bair the Ridicule of the World." His difficulties were not diminished by the fact that he was an anti-Federalist and a Deist.[50] His more conventional rival, James Rumsey, who independently and in secret invented the steamboat about the same time, also met ridicule and disparagement.

Robert Fulton made a commercial success of the steamboat and was acclaimed. But a note written in 1807 shows how his work was scorned while he was experimenting:

> When I was building my first steamboat, the project was viewed by the public either with indifference, or with contempt, as a visionary scheme. My friends, indeed, were civil, but they were shy. They listened with patience to my explanations, but with a settled cast of incredulity on their countenances. As I had occasion daily to pass to and from the shipyard while my boat was in progress, I have often loitered unknown near the idle groups of strangers, gathering in little circles, and heard various inquiries as to the object of this new vehicle. The language was uniformly that of scorn, sneer, or ridicule. The loud laugh often rose at my expense; the dry jest; the wise calculation of losses and expenditures; the dull but endless repetition of "Fulton's folly." Never did a single encouraging remark, a bright hope, a warm wish, cross my path. Silence itself was but politeness, veiling its doubts, or hiding its reproaches.[51]

Those who loaned him money to continue his plans on the steamboat stipulated that their names be withheld for fear of ridicule and loss of status were it known that they supported so "foolhardy" a project.

The idea of propelling ships by steam met opposition in England and on the Continent as well. In 1804, a bill was introduced in the House of Commons at the instance of the British Admiralty, against the introduction of steam power in the British navy. England had only 20 steamers by 1815, and it was not until 1833 that Britain built her first steam-driven warship. The first steamer on the Continent was one that ran between Paris and Rouen in 1816. There were no steamers on the Rhine or the Elbe until 1818, nor on the Danube until 1830.[52]

Other advances in marine transportation met resistance. The United States Navy hesitated about adopting Ericsson's screw propeller.[53] "Incredulously and pityingly they [shippers and shipbuilders] often looked upon me", writes Flettner, "and they often shrugged their shoulders when I mentioned that in a storm or hurricane this free rudder thrown about by the huge waves would swing back and forth without the steadiness of the ship's course being affected in the slightest degree * * * they even looked upon me as an impractical dreamer."[54]

Although the first iron barge had been made to float in Yorkshire in 1777, arguments against the use of iron ships continued for decades. Wilkinson wrote in 1787, when his iron boat was launched: "It answers all my expectations, and has convinced the unbelievers who were 999 in a thousand. It will be only a 9-days wonder and then will be like Columbus' egg." But the relative cheapness of wood, the early difficulties involved in preparing iron plate, and the opposition of the powerful shipbuilding interests, long delayed the building of iron ships. Men continued to insist, moreover, that iron ships would not float, that they would damage more easily than wooden ships when grounding, that it would be difficult to preserve the iron bottoms from rust, weeds, and barnacles, and that iron would deflect the compass.[55] Ericsson's plan for the *Monitor* was first rejected by the United States Navy because it was claimed that this iron battleship lacked stability.

Leonardo de Vinci records that he suppressed his invention of the submarine because "it was too satanic to be placed in the hands of unregenerate men."[56] The inventor of the submarine, John P. Holland, was considered insane for his persistent experiments with under-water transportation. The fact that the experiments were financed with money of the Fenian move-

[49] Quoted in Boyd, op. cit. p. 229–230.
[50] Boyd, op. cit. p. 187, 205.
[51] Iles, George, Leading American Inventors (New York, 1912), p. 60–61.
[52] Boehn and Fischel, op. cit. vol. ii, p. 24–26.
[53] Iles, op. cit. p. 232.
[54] Flettner, Anton, Mein Weg zum Rotor (Leipzig, 1926) tr. by F. O. Willhofft as The Story of the Rotor (New York, 1926), p. 19.
[55] Gilfillan, S. C., Inventing the Ship (Chicago, 1935), p. 149.
[56] Mumford, Lewis, Technics and Civilization (New York, 1934), p. 85

ment which sought to free Ireland from British imperialism enhanced the ridicule and skepticism that greeted his work.[57] H. G. Wells joined the popular disparagement of submarine, writing: "I must confess that my imagination, in spite even of spurring, refuses to see any sort of submarines doing anything but suffocate its crew and founder at sea." [58] By 1898 Holland had built a successful submarine which was sold to the United States Government. It was not however, until the World War that the submarine came generally into use.

Airplane.—Attitudes toward the possibility of the invention of the airplane went beyond healthy skepticism even on the part of engineers and scientists. The early trials which ended in disastrous failure and the many fantastic attempts to realize man's hopes to imitate the birds gave grounds for doubt of success and occasioned ridicule of those that hazarded. In 1871, the New York Times proclaimed editorially that there was "abundant precedent for the supposition that the laws of gravity will always prove too much, in the aerial field, for the ambitious dexterity of man." [59] Later when Professor Samuel Pierpont Langley, secretary of the Smithsonian Institution, predicted early establishment of an air transportation that could attain unprecedented speeds, the Popular Science Monthly rebuked him, saying:

> The secretary of the Smithsonian Institution should be the representative of American science and should be extremely careful not to do anything that may lend itself to an interpretation that will bring injury on the scientific work of the Government or of the country * * *. He could have placed his scientific knowledge at the disposal of Army officers and expert mechanicians, and this would have been better than to attempt to become an inventor in a field where success is doubtful and where failure is likely to bring discredit, however undeserved, on scientific work.[60]

An editorial in the New York Times in 1904 saw no possible objection if those interested in flying cared to indulge in "airy persiflage" across the "walnuts and wine", but averred that they "should not expect those who have not dined with them to take them quite seriously." [61] Simon Newcomb's attitude was defeatist. He did nothing to use his scientific authority to stimulate further research, in fact discouraged it, at a time when success was just in the offing, by his widely publicized statement:

> The demonstration that no possible combination of known substances, known forms of machinery, and known forms of force can be united in a practicable machine by which men shall fly long distances through the air, seems to the writer as complete as it is possible for the demonstration of any physical fact to be.[62]

Helmholtz likewise questioned the possibility of the success of a heavier than air machine.[63] H. G. Wells acknowledged that air flying would be mastered, but he failed to see its possibilities declaring: "I do not think it at all probable that aeronautics will ever come into play as a serious modification of transport and communication." [64]

With the invention of the light-weight internal-combustion engine, successful airplanes were flown. Yet the British War Ministry refused to negotiate with manufacturers of airplanes in 1907, 2 years after Wright's first flight was officially recorded and 4 years after his first actual flight.[65] Previous to April 1926, when it established a separate class for aircraft, the German Patent Office had the same classification for airplanes as for children's toys, popular amusements, and shooting galleries.[66]

It has not been merely fear of flying that has delayed the popular use of flying as a means of transportation. The establishment of airdromes at great distances from the centers of large cities because of the high prices demanded for the land by property holders has contributed toward retarding the development of air service. The owners of existing transportation services, the railroads, steamboats, and autobus lines, as well as automobile manufacturers have propagandized against the extension of air routes. Recently in Alaska the drivers of dog teams and those that sold them fish, were vigorous in their opposition to air mail service. Established airplane companies have discouraged new capital from entering the field as is reflected in an editorial in the Business Chonicle, January 27, 1930:

> The airplane business is to gravitate into control of comparatively few strong corporations as has the manufacture of automobiles. The day for creation of new factories doubtless passed during 1928 and 1929. A few infant industries to supply airplane materials might yet gain foothold in Pacific Coast States, but community boosters will do wisely to move very slowly now in encouraging any new plane manufacturing enterprise. In most cases the money and effort can better be devoted to some other more promising project.[67]

Communication

Writing.—Innovations in the field of communication have likewise been opposed at every step, in spite of their utility in diffusing and perpetuating knowledge and thus augmenting man's control over his en-

[57] Talbot, op. cit. p. 71–84.
[58] Wells, H. G., Anticipations (London, 1902), p. 217.
[59] New York Times, June 25, 1871.
[60] The Progress of Science: Aerial Navigation, in Popular Science Monthly, vol. lxiv (1903–4) 95–96.
[61] Quoted in editorial in New York Times, Mar. 30 1931.
[62] Newcomb, Simon, Sidelights on Astronomy (New York, 1906), p. 345.
[63] Flettner, op. cit. p. 92.
[64] Wells, op. cit. p. 35.
[65] Literary Digest, vol. xciii (June 25, 1927), p. 9.
[66] Flettner, op. cit. p. 92.
[67] Business Chronicle, vol. xxx (1930), p. 1.

vironment. Priestly classes in many early societies resisted the recording of tradition in writing, and the extension of literacy has frequently been opposed by ruling classes as a ferment to discontent.

Writing as a conserving instrument is itself extremely conservative. Scripts acquire highly emotionalized attachments, and become identified with cultural and nationalist symbolism. The result is that styles of writing and alphabets become tenacious. The ancient and medieval scripts prevailed for over five centuries, the Gothic for over eight centuries, and is today being revived in Nazi Germany. Even when one script displaces another, the older form persists in use for special purposes.[68] Organized resistance has been made to changes in alphabets as when the elimination of three letters from the Bulgarian alphabet in 1922 provoked the resignation of two ministers.[69] The Latinizing of the Turkish alphabet was strenuously opposed especially in religious circles. Simplified spelling has aroused not only ridicule and disparagement, but at times bitter resentment.

The same conservatism is evident in numerical notation. In 1299 an edict was issued in Florence forbidding bankers to use Arabic numerals, and Roman numerals are still widely used especially for ceremonial purposes.[70] Continued use of Newton's notation by English mathematicians throughout the eighteenth century, and even by many English writers on mechanics today, while the French and German mathematicians usually employed that of Leibnitz, created a barrier between English and Continental mathematics that impeded their development.[71] Opposition to the enforced or even optional use of the metric system of measurements in the United States has been based on sentimental appeals to a poetic tradition and postulated superiority of the English system as well as upon arguments based on the costs of the change. An attempt by leading silk merchants in Foochow to adopt a standardized lineal measure failed because most of the merchants refused to use it, and there remain in China several kinds of units of lineal measure—the Shanghai foot, the tailor's foot, the carpenter's foot, and the engineering foot—all of differing lengths.

Printing.—The spread of block printing westward from China was checked by the opposition of the Islamic world. Resistance arose among the calligraphers in the scriptoria of Cordova and in other Islamic cultural centers where there was large scale production of superb texts, far superior in artistic merit to the products of early printing. When permission was granted in 1727 for the establishment of a printing press in Constantinople, with the proviso that the Koran should not be printed, the venture none the less aroused such intense opposition that it was abandoned and printing was not introduced again for about a century. The Koran was never printed in any Islamic country until a few years ago. The reason given was the belief that to touch the name of Allah with a cleaning brush made of hog bristles was blasphemy. In India, the Brahman caste successfully resisted the introduction of printing until a printing press was set up at Goa by the Portuguese late in the sixteenth century.[72] The introduction of printing was delayed in Paris 20 years by the hostility of the guild of scribes.

The first printed books were crude, costly, and inferior to the artistic work of the skilled calligraphers of the guilds, and therefore resistance is easily explicable. But even as printing improved, there was, for a long time, little realization of its possibilities as an agency in the dissemination of knowledge and propaganda. When this realization came, printing was hedged in by drastic governmental restrictions, often initiated by church authorities, as when Leipzig printers were forbidden to print Protestant literature for about two decades.[73] A widespread sentiment against printing was expressed by Governor Berkeley of Virginia, when he said in 1670: "* * * I thank God there are no free schools, nor printing, and I hope we shall not have them these hundred years; for learning has brought disobedience and heresy and sects into the world, and printing has divulged them and libels against the best government." [74]

Types, as in the case of scripts, are exceedingly conservative and become surcharged with emotional tones that form the basis of intense resentment to changes. Many newspapers and magazines retain the same types and formats for long periods after they have become outmoded, in order not to alienate their readers.

New machinery in the printing industry in the composing room, the pressroom, and the bindery, has been delayed by the costs involved in the obsolescence of old equipment and by workers faced with unemployment. When the stereotyping machine was first introduced by William Ged in Edinburgh in 1725, opposition was so strong that it was discontinued. The linotype machine, which, when originally patented, was not regarded by printers as a practical machine, supplanted

[68] Stern, Bernhard J., Writing in Encyclopaedia of the Social Sciences, vol. xv (New York, 1935), pp. 500–502.

[69] Ullmann, B. L., Ancient Writing and Its Influence (New York, 1932), p. 221.

[70] Taylor, Isaac, The Alphabet, 2 vols. (London, 1883), vol. II, p. 263.

[71] Wolf, Abraham, History of Science and Technology in the 16th and 17th Centuries (London, 1935), p. 217.

[72] Carter, T. F., The Invention of Printing and Its Spread Westward (rev. ed. by D. C. McMurtrie, New York, 1931), pp. 112–113.

[73] Duffus, R. L., "Printing and Publishing" Encyclopaedia of the Social Sciences, vol. xxi (New York, 1934), pp. 406–415.

[74] Quoted in Simons, A. M., Social Forces in American History (New York, 1911), pp. 47, 48.

straight matter typesetting by hand slowly between 1886 and 1903, without strenuous opposition on the part of labor because of agreements with the printers' unions over employment and output. Mechanically fed platen and cylinder presses were adopted gradually in commercial printing, comprising less than 4 percent of presses in 1913 and still only 66 percent in 1921.[75] Printers have led the opposition to lithographing and photographic processes that compete with them.

Typewriter.—For a long time after the typewriter was actually produced for sale in 1874, the response to it was apathetic when not overtly hostile. The question of costs loomed large. Many questioned the value of paying approximately $125 for a machine that would do the same work as a 1-cent pen. The description of the early typewriter given by J. G. Priestly clearly indicates one of the causes in the delay of its reception: "It (the typewriter) had the old double keyboard—typing then was a muscular activity. If you were not familiar with these vast keyboards, your hand wandered over them like a child lost in a wood. The noise might have been that of a shipyard on the Clyde. You would no more have thought of carrying about one of those grim structures than you would have thought of travelling with a piano." [76]

The value of the typewriter in commercial activities was hardly glimpsed even after it became more efficient. Questions of the status of women in society and of etiquette became involved in the controversies over its utilization. The girl typist became a symbol of women's emancipation and aroused responses accordingly. In 1881 when the New York Y. W. C. A. announced typing lessons for women, vigorous protests were made on the grounds that the female constitution would break down completely under the strenuous 6 months' course offered. As for etiquette, it was, and still is in some quarters, considered bad taste to use the typewriter for personal letters. The machine was long looked upon as affectation, a pretense to authorship or professionalism on the part of a layman. Some people looked upon the receipt of typed letters as an aspersion upon their literacy. All these factors tended to delay the wide utilization of the typewriter until recent years.

The production of typewriters is highly concentrated and there is no outlet for patents on new inventions except through a few manufacturers. Such monopolistic control is also characteristic of the mimeograph industry where the dominant corporation which controlled, in 1915, 85.1 percent of the commerce in the United States in stencil duplicating machines, has suppressed innovations by compelling the users of such machines to purchase stencil duplicating paper, ink, and other duplicating supplies exclusively from them.[77]

Telegraph and Telephone.—There was an indifferent response to Morse's invention of the telegraph patented in 1837. Few were interested when he exhibited it, for its uses were not comprehended and it was regarded merely as a scientific toy. When Morse first asked for $30,000 as a governmental appropriation for an experimental telegraph line, it was regarded by some of the legislators as fantastic. One suggested that half that sum be spent on mesmerism and another that Millerism be the recipient of the other half. Morse was finally awarded the appropriation in 1843 by a margin of eight votes. Later the Government declined to buy the invention for $100,000. The first apparatus was clumsy, with a weight of 185 pounds as compared to less than 4 ounces in 1912. So little confidence did the public have in the telegraph that 2 years after the line had been installed, the receipts for one quarter were only $203.43 at the rate of 1 cent for four characters.

In England, where the British Admiralty had declared in 1816 that telegraphs were totally unnecessary, Morse's telegraph met the opposition of a rival method. Wheatstone and Cooke's needle instrument, which required two lines to complete a circuit, had already been installed. On October 9, 1845, Morse wrote:

> I have many obstacles to contend against, particularly the opposition of the proprietors of existing telegraphs. But that mine is the best system, I have now no doubt; all that I have seen, while they are ingenious, are more complicated, more expensive, less efficient, and easier deranged. It may take some time to establish the superiority of mine over the others, for there is the usual array of prejudice and interest against a system which threws others out of use.[78]

The telegraph companies, once entrenched, did not encourage and were slow to respond to the innovations in their own and related fields. They did not encourage the invention of the cable and even after the first cable had been laid they continued their efforts to have transoceanic communication by way of Alaska and Siberia. Neither the telegraph nor the cable companies invented the telephone. Bell's offer to sell it to the Western Union Telegraph Co. for $100,000 was rejected. In 1883 eight leading business men in New York City met to decide whether to buy rights to the Bell telephone or the printing telegraph, both of which were offered at the same price, $300,000, and they decided to buy the latter.[79] When the telephone

[75] Baker, E. F., Displacement of Men by Machines (New York, 1933), pp. 15, 16.

[76] Priestley, J. B., English Journey (London, 1934), pp. 122–123.

[77] Federal Trade Commission, Annual Report for the Fiscal Year Ended June 30, 1917 (Washington, D. C., 1917), pp. 60, 61.

[78] Iles, op. cit. p. 160, 164, 167.

[79] Fessenden, R. A., "The Inventions of Reginald A. Fessenden" in Radio News, vol. vi (1925), 1140–1142, 1851–1853, 1999.

began seriously to compete with the telegraph, and to menace its interests, the telegraph companies accentuated public skepticism by a campaign of ridicule and disparagement. The inventor was characterized as a crank and a charlatan. His work was the devil's work, disturbing the tranquillity of the countryside, and inducing break-downs among its users. The widespread currency of this attitude even among the sophisticated is seen in Thorstein Veblen's statement as late as 1914 that the use of the telephone "involves a very appreciable nervous strain and its ubiquitous presence conduces to an unremitting nervous tension and unrest wherever it goes."[80] Imperfections in the apparatus and in service were stressed. The plan to connect cities, villages, and isolated homes into one comprehensive system was denounced as folly.

The monopolistic control over the basic telephone patents which the Bell corporation acquired made it impossible to introduce improvements without its sanction. Thus when Edison, Blake, and Berliner improved the Bell telephone, their important contributions could not be utilized without the basic invention, and so they came under the control of the owners of Bell patents.[81] In 1937, the Federal Communications Commission declared that the Bell Telephone System suppressed 3,400 unused patents in order to forestall competition. Of these, 1,307, it said, were "patents voluntarily shelved by the American company and its patent-holding subsidiaries for competitive purposes." In answer to the company's declaration that the other 2,126 patents were not used because of "superior alternatives available", the Commission reported: "This is a type of patent shelving or patent suppression which results from excessive patent protection acquired for the purpose of suppressing competition. The Bell System has at all times suppressed competition in wire telephony or telegraphy through patents. It has always withheld licenses to competitors in wire telephony and telegraphy under its telephone and telephonic appliance patents, and this exclusion is extended to patents covering any type of construction. Moreover the Bell System has added to its * * * patents any patent that might be of value to its competitors. This policy resulted in the acquisition of a large number of patents covering alternative devices and methods for which the Bell System has no need. * * *

"Provisions tending to suppress development are found to be present in patent license contracts between the Western Electric Co. and independent manufacturing companies."[81a]

Automatic telephone switchboards were introduced slowly. The chief engineer of a leading telephone company denounced the automatic system before the American Institute of Electrical Engineers. It was difficult for the public to orientate itself to the automatic system. The United States Senate, for example, had a new dial telephone system removed after a short trial. There were protests by workers against the installation in terms of technological unemployment. But the delay was chiefly occasioned by the depreciation costs on obsolete equipment. Similarly, the cradle or French telephones were long in use on the Continent before they were installed in the United States and then a service charge was added largely in order to retard their introduction.

The telephone, cable, and telegraph companies did not invent the wireless telegraph; they at first declined to purchase it and later sought to suppress it. Jealous rivalry between the Italian and the German wireless telegraph systems led the German company to refuse to accept messages dispatched from German ships equipped with the Marconi instruments. The Italian company retaliated and service was crippled. As a result of this type of competition telegraphy was discredited for a number of years.[82]

The telegraph, cable, and wireless companies declined to purchase the wireless telephone.[83] DeForest recounts the great difficulties he had promoting his wireless telephone. He writes that when he exhibited his experiments in this field before five engineers of Western Electric Co., months passed and he heard nothing from them. Refused by bankers, he sought to raise money from his classmates of the Yale Class of 1896; he succeeded in raising only $500.[84]

There were vast time lags between the discovery of the scientific principles underlying radio by Joseph Henry, Hertz, Lodge, and others and the practical application of these finds. Even when in 1907 DeForest put the radio tube in workable form at the same time as others had made like inventions independently, he was unable to sell his patent and let it lapse rather than pay $25 for its renewal.[85] The beginnings of radio were very crude, and there appears to have been no anticipation at all of its extensive development when the first broadcast occurred in 1920. Patent litigation in the radio industry particularly as between

[80] Veblen, Thorstein, The Instinct of Workmanship (New York, 1914), p. 316.

[81] Vaughan, F. L., Economics of our Patent System (New York, 1925), p. 72.

[81a] Federal Communications Commission, Patent Study of Bell Telephone System, Special Docket No. 1, 1937 (Washington, D. C., 1937).

[82] Talbot, op. cit. p. 24.

[83] Fessenden, op. cit. p. 1140.

[84] Carneal, Georgette, A Conqueror of Space (New York, 1930), p. 204.

[85] Agnew, P. G., "Harnessing Scientific Discoveries" in Scientific Monthly, vol. xl (1935) 170–173.

the Armstrong patent controlled by Radio Corporation of America and DeForest patents, with repeated reversals of the courts, made the ownership of the patent rights uncertain. This delayed the development of radio because of the fear of infringement suits. Concentrated control makes it imperative that all radio inventions clear through a few companies if they are to be marketed successfully, which involves their suppression when the new inventions disturb existing market conditions. Competition between newspapers and radio for advertising has repeatedly and in diverse ways interfered with the full utilization of radio facilities.

Rivalry between monopolistic groups for its control led to the recent opposition to the construction of the coaxial cable between New York and Philadelphia, over which 2,400 telegraph messages may be sent at one time, and which can carry a band of frequencies of at least one million cycles. It was argued before the Federal Communications Commission by the Western Union and Postal Telegraph & Cable companies, as well as by broadcasting companies that its use would disrupt existing communication and broadcasting services. After rehearings, each involving delays, during which the American Telephone & Telegraph Co. sought to use the cable exclusively, the F. C. C. ordered against monopolistic control.[86]

Power

Steam Engine.—There were many anticipations of the steam engine that remained unfulfilled. Hero of Alexandria (c. 50 A. D.) in his treatise on pneumatics, describes a machine which, by means of an altar fire, could be made to open temple doors, another which produced a steam jet on which a light ball could be supported, and an aeolipile which was essentially a reaction steam turbine. With the prevailing economic situation and attitude toward practical and mechanical activity in ancient Rome, the significance of his inventions was not appreciated. Steam was used in the tenth century by Sylvester II to operate an organ. The Italian chemist, Branca, used a jet of high pressure steam to turn a paddle wheel; his plan showed the boiler in the form of the head and body of a man. Kircher, Jesuit philosopher, in Rome; Baptista Porta, the mathematician, in Naples; and Solomon de Caus, the French architect and engineer, all operated fountains by steam in the sixteenth century. The English bishop, Wilkins, a brother-in-law of Oliver Cromwell, made experiments with acolipiles. But there was then no conception of steam as an industrial motive power.

In 1663, Edward Somerset, second Marquis of Worcester, obtained rights for 99 years by act of Parliament, for his "water commanding engine" the first serious attempt known to make practical use of steam. But he, and his widow following him, were unsuccessful in forming a company to develop his invention. Thomas Savery around 1698 invented an engine designed to deal with accumulation of water in the Cornish mines. He circulated a pamphlet in 1702 among the mining operators—one of whom had to use 500 horses in raising water by horsegins and buckets—entitled "The miner's friend, or an engine to raise water by fire, described, and of the manner of fixing it in mines, with an account of several other uses it is applicable unto; and an answer to objections made against it." But his machine was costly, wasteful, and dangerous, largely because no one knew how to make boilers and pipes strong enough to resist the requisite steam pressure, and so the miners continued to use their horses. In 1712 Thomas Newcomen announced his epoch-making atmospheric steam engine to pump water, but it failed to create any significant amount of public comment or excitement. James Watt, who worked under the patronage of Dr. John Roebuck, a wealth industrialist, got a patent in 1769 on what was originally only an improvement of the Newcomen engine. By an extension of his patents until 1800 by an act of Parliament, he acquired a monopoly on the steam engine that, as Watt himself admitted, killed all further invention in this field in England until the next century. (For opposition to the application of the steam engine in the textile industry see p. 55.) The restrictive laws of Great Britain which prohibited machinery from being exported, delayed the development of the steam engine in other countries. Watt opposed the development of higher pressure engines, and was limited in his vision as to the uses of his invention [87] (see p. 40).

The invention of an efficient steam engine in Russia in 1763 by Ivan Ivanovich Polsunov was acknowledged by an award from Empress Catherine, but was stillborn in an industrially backward setting.[88] In the United States, Oliver Evans was granted rights on flour-mill machinery driven by steam, in 1786 by Pennsylvania, and in the following year by Maryland. But not a single miller in Maryland, Pennsylvania, Delaware, or Virginia, would purchase "such rattle traps." [89] The introduction of power machinery in shoe-making was vigorously opposed by the Lynn Laster's Union in Lynn, Mass. Ericsson demonstrated, in 1828, the effectiveness of a steam fire engine in London but municipal authorities decided against the

[86] New York Times, May 25, July 16, July 25, 1935; Jan. 7, Feb. 27, 1936.

[87] Wolf, op. cit. p. 543–556; Mitman, op. cit. p. 507–515; Dickinson, H. W., James Watt (Cambridge, England, 1936), pp. 43, 45, 57.

[88] Vasilevsky, E. M., The Land of Inventors (Moscow, 1933), p. 30.

[89] Mitman, op. cit. p. 531.

engine and pumping was done by hand for 32 more years.[90]

Coal.—Coal encountered strenuous opposition before it was accepted as a fuel. It was denounced in London during the reign of Edward I as a "public nuisance, corrupting the air with its stink and smoke, to the great detriment of their health", with the result that the king prohibited its use and in 1306 a citizen was tried, condemned and executed for burning "sea cole."[91] In 1580 Queen Elizabeth prohibited the use of coal in London while Parliament was in session, because "the health of the knights of the shires might suffer during their abode in the metropolis." A "health tax" was imposed on fireplaces by King Charles II in 1662.[92]

In the United States coal was discovered in Richmond, Va., in 1702, but the mines were not opened until 1750. As late as 1795 coal users were ridiculed.[93] Wherever wood was in abundance, the utilization of coal was delayed.

Gas.—Opposition to the use of gas for lighting when it was first introduced in the beginning of the nineteenth century had manifold roots. There were fears of fires and suffocation, which, though sometimes based on ignorance of the process involved, were often well grounded because of the defective methods of transmission causing frequent leaks and fatal explosions. But numerous other arguments were adduced. One group of objectors declared that the use of gas would deprive Britannia of her ability to rule the waves, because by eliminating whale oil lamps it would destroy the whale oil industry, the nursery whence Britain drew her sons to man her fighting ships. This line of reasoning sounded cogent to many, as the Napoleonic Wars were then being waged.

Relentless opposition arose when Samuel Clegg and Frederick Albert Winsor sought Parliamentary sanction for their plan for a central gas distribution system to supply gas for private dwellings, factories, public buildings and thoroughfares. Their application for the incorporation of the London and Westminster Chartered Gas Light & Coke Co. was vehemently assailed. Scientists led the opposition by ridiculing the plan to store gas in reservoirs. Sir Humphrey Davy thought the plan impractical and sarcastically asked whether Clegg intended to use the dome of St. Paul's Cathedral as a gas-holder. Wollaston and Watt and the Royal Society likewise declared the project not feasible. Financiers and insurance companies ranged themselves in opposition and cited in proof a disastrous explosion that had occurred in London. Street-lamp lighters went out on strike. Parish authorities announced their intention of uprooting any lampposts and pikes planted in the streets within their jurisdiction. Caricaturists such as Cruikshank and Rowlandson satirized the plan, as did Byron. Sir Walter Scott wrote to a friend in incredulous amazement: "There is a madman proposing to light the streets of London—with what do you suppose—with smoke." Lighting with candles and torches was lauded as picturesque. Gas was denounced as a symbol of commercialism studding the landscape with unsightly reservoirs. The charter was finally granted in 1810, but it was not until 3 years later that the public accepted the new system of lighting.[94]

Opposition to gas lighting was not restricted to England, but arose in some degree in all countries. Napoleon characterized the idea as *une grande folie* and when Paris attempted to introduce the new system in 1818, it met with little favor.[95] Berlin did not install a gas system until 1823, and the streets were not lighted by gas until 1826. The bursting of the gas lanterns on the day it was introduced on Unter den Linden gave those who had predicted failure temporary elation.[96]

Gas was installed in Baltimore in 1821, but it was many years before popular prejudice was allayed against gas as a danger to health and safety, and the skeptical ceased to frown upon its efficacy. As late as 1833, a petition to the Philadelphia Common Council warned against the use of gas "as ignitable as gunpowder and as nearly fatal in its effects as regards the immense destruction of property." It was also argued that the city should continue to be lit with oil, because the discharge of the tar from the gas works into the surrounding waters might drive away the shad and herring.[97] It was accepted with much more alacrity in the new cities where extensive street lighting systems had not already been set up, and there were no losses incurred through obsolescence. Long after gas became generally accepted as a means of illumination, churches continued the use of candles and oil. The lights of the Roman Catholic Cathedral of Westminster are still relit at Easter by flint and steel, although a modern mechanical device is used.

Improvements in gas lighting also met resistance. Welsbach gas mantles were invented in 1885, but

[90] Iles, op. cit. p. 222–23.

[91] Masson, E. O. and Chubb, L. W., "Smoke" in Encyclopaedia Britannica, 11th ed., vol. xxv (1911), p. 275.

[92] Norman, O. E., The Romance of the Gas Industry (Chicago, 1922), p. 160.

[93] Darrow, F. L., "Buried Sunshine—The Story of Coal" in Kaempffert, W., ed., A Popular History of American Invention, 2 vols. (New York, 1924), vol. II, p. 116–117.

[94] Talbot, op. cit. p. 49–58; Timbs, John, Wonderful Inventions (London, 1868), p. 172.

[95] Luckeisch, M., From Rushlight to Incandescent Lamp in Kaempffert, W., ed., Modern Wonder Workers (New York, 1921), pp. 546–547.

[96] Boehn and Fischel, op. cit. vol. II, pp. 145–147.

[97] Luckeisch, op. cit. p. 554.

largely because of their costs they were not used extensively until 1890, although they gave a better light with lower gas consumption.[98]

Electricity.—Early experiments with electricity were ignored or ridiculed. Franklin's letters to Collison, which described his experiment with the kite that charged a Leyden jar by electricity drawn from the clouds, performed in June 1752, were read before the Royal Society, but remained unnoticed.[99] Galvani, engaged in 1762 in experiments with reactions of frogs' legs to electric shocks, is reported to have said: "I am persecuted by two classes: The scientists and the know-it-alls. Both call me 'the frogs' dancing master.' Yet I know that I have discovered one of the greatest forces of the universe."[1] The possibilities of electricity were seen by Faraday in 1832, but before efficient generators of large size were produced on a commercial basis the steam engine was firmly established and the costs of obsolescence in steam manufacturing equipment delayed their wide use.

The electrical companies themselves were long remiss in understanding the uses to which electricity could be put. The chief engineer of one of the largest electrical companies declared that "electricity could never be used except as an auxiliary on shipboard." The high-frequency alternator was not invented by the electric companies and when one was made up at the inventor's expense, an electric company returned it with a letter stating that in the opinion of its engineers "it could never be made to operate above 10,000 cycles."[2]

It can hardly be said that Edison's invention of the incandescent lamp was universally acclaimed. The issue of the New York Times of December 28, 1879, in which Edison's demonstrations at Menlo Park are described, carried a statement of Prof. Henry Morton, the president of Stevens Institute of Technology, protesting against the trumpeting of the results of Edison's experiments in electric lighting as "a wonderful success" when "every one acquainted with the subject will recognize it as a conspicuous failure." He declared that Edison "has done and is doing too much really good work to have his record defaced and his name discredited in the interests of any stock company or individual financier." He then predicted the failure of the lamp inasmuch as all previous attempts had been failures. Other scientists denied the possibility that carbon could be used for filaments because carbon contained the elements of its own destruction. The managing editor of the New York Herald rebuked the city editor of his paper for publishing a feature article on Edison's electric light on the grounds that such a light was against the laws of nature.[3]

Early demonstrations by Edison of the incandescent lamp disturbed the London stock exchange. Uneasiness on gas share quotations in one day amounted to a veritable panic because the sensational reports in the press led to the belief that gas was to be superseded entirely.[4] But gas lighting yielded slowly to electricity. The expense involved in making and operating the lamps which were very short lived seemed to many to negate any prospect of their wide use.[5] By opposing franchises for electrical lighting, the gas companies retarded its application. Gas lighting was put forward as the model of safety and electricity was denounced as hazardous. Those installing electricity in dwellings were often obliged to use fixtures permitting the use of gas as well. Dim gas street lighting was characterized as romantic as contrasted with the glare of electric lighting and the lamplighter was sentimentalized. As late as June 27, 1929, when gas lights were to be replaced in various parts of San Francisco, a local paper in a news report said: "Many people view the passing of the gas light with regret, because the lamplighter—either a young man working his way through school, or an old man trudging by at sunset—was a personality. Especially on Russian Hill the people are not anxious for speedy substitution of new lights. They feel that the gas lights fit the Bohemian character of the neighborhood."

Changes within the electric industry have been retarded by the buying and suppressing of patents by the large corporations which dominate the field. From 1896 to 1911 the General Electric and the Westinghouse electric companies had a patent-purchasing agreement that neither would acquire a patent that would tend to injure the other, and many inventors could not find a market for their patents.[6] A superior electric lamp, which it is estimated will save electric light users $10,000,000 a year, has been invented but has not been put on the market.[7]

For household uses the wood range held out a long time against the coal range and the oil burner. In turn the coal range has resisted the gas range, and the gas range the electric range.

Metals

When the artificers among the early Europeans first used copper for tools and weapons, they did not

[98] Norman, op. cit. pp. 54–55, 171.

[99] Thompson, Holland, The Age of Invention, The Chronicles of America Series, vol. xviii, pt. i (New Haven, 1921), p. 11.

[1] Quoted by Hart, op. cit. p. 629.

[2] Fessenden, op. cit., p. 1140.

[3] White, F. M., "Edison and the Incandescent Light" in Outlook, vol. xciv (1910), 487–488.

[4] Byrn, E. W., The Progress of Invention in the Nineteenth Century (New York, 1900), p. 71.

[5] Usher, A. P., A History of Mechanical Inventions (New York, 1929), p. 366.

[6] Vaughan, op. cit. p. 210–211.

[7] New York Times, Jan. 2, 1936, p. 50.

sense the possibilities of the metal and their copper celts closely resembled the shape of the stone celts. Iron was long regarded with suspicion, and there were protracted delays before it was utilized in the place of bronze and stone. Certain tribes of East Africa, among them the Akamba, retain their objection to the iron hoe which they believe keeps away the rain. Iron was not worked by the Caribou Eskimos during the musk ox hunting season, and the Kadiak Eskimos continued to use slate spearheads because of the belief that they brought on death more quickly than iron spearheads.[8] In the Biblical story of the building of Solomon's temple, it is declared that the sound of iron tools was not heard,[9] and the Mormon temple at Salt Lake City was built without iron. No bolts or iron were permitted in the repair of the Publican Bridge across the Tiber as late as the fall of the Roman Republic.[10] Stone knives were used by the Jews for circumcision and by the Egyptians for embalming, long after they were familiar with iron. The first successful cast-iron plow invented in the United States in 1797 was rejected by New Jersey farmers under the theory that cast iron poisoned the lands and stimulated the growth of weeds.[11]

The prohibitive price of wrought iron prevented its wide utilization. In 1591 a forge could not make more than 2 tons a week, and owing to a shortage of water often made only 50 tons a year. Water tanks and pipes therefore continued to be constructed in pewter and lead. Savery's engines seem to have failed because the lead pipes burst under the pressure he applied. Even at the close of the seventeenth century the product of the forges was often insufficiently decarbonized and crumbled when hammered.[12]

Abraham Darby's discovery in 1709 of how to eliminate the bad effects of the sulphurous fumes of coal in making iron was practically ignored. In France, Réaumur's process was neglected for many years. Henry Cort, who took out patents on the use of coal in forges and on the processes of puddling and rolling in 1783 and 1784, went bankrupt. An official report of the British government of his patents said in 1805: "It does not seem that any opportunity has occurred, though endeavors have been used, to make them available to any profitable purposes." The influence of early inventions was so negligible that a member of the House of Commons could declare in 1806, nearly a century after Darby's discovery, and over 20 years after Cort's discoveries: "Formerly and till within the last 5 or 6 years, wood or charcoal was the only material by which it was supposed that iron could be made; but the ingenuity of the manufacturers led them to find a substitute in coak." [13]

When, in 1856, Bessemer at Cheltenham made public his process of making steel, many iron makers accepted his convertors readily, but their early efforts to produce steel proved a dismal failure because of the chemical composition of the pig iron which contained too much phosphorus. Bessemer repurchased the patents and after a short period of experimentation he discovered the causes of the previous failure, and began to manufacture the steel himself. For a time, however, his product appeared to be a drug on the market. His firm did little business during its first 2 years, for the trade was slow to acknowledge the virtues of the new metal partly because of the failure of its first commercial exploitation.[14] In the United States, when, in 1846, William Kelly discovered independently the same process as Bessemer, his father-in-law, who believed the method ridiculous, and such experimentation harmful to the credit of his iron works, threatened to withdraw his financial support. Customers rejected the new product and insisted on iron refined by the regular methods.[15]

The United States Steel Corporation has initiated few technological changes in the steel industry, and has been slow to respond to innovations. It rejected or neglected, largely because of its vast investments in other processes, Henry Gray's invention of a structural section that could be rolled together in one piece; John B. Tytus's method of manufacturing steel sheets by a continuous process like that used in the manufacture of paper; Gayley's process of supplying a dry blast to blast furnaces; the new centrifugal process of casting ingots which eliminates ingot molds, soaking pits and blooming mills. It lagged in the development of the stainless steel market. Because its prices are calculated in tonnage, it has discouraged and has refused to experiment or pioneer in alloy steels which make possible reduction in the weight of steel without sacrificing strength.[16] Louis D. Brandeis in 1914 cited with approval the judgment of the editor of Electrical News:

> We are today something like 5 years behind Germany in iron and steel metallurgy, and such innovations as are being introduced by our iron and steel manufacturers are merely following the lead set by foreigners years ago. We believe the main cause is the wholesale consolidation that has taken place in American industry. A huge organization is too clumsy

[8] Sayce, R. U., Primitive Arts and Crafts (Cambridge, Eng., 1933), p. 182, 185, 193–194.
[9] 1 Kings, 6 : 7.
[10] Burgess, E. W., The Function of Socialization in Social Evolution (Chicago, 1916), p. 16.
[11] Thompson, op. cit. p. 112.
[12] Wolf, op. cit. p. 542.
[13] Hammond, J. L., and Barbara, The Rise of Modern Industry (London, 1925), p. 137, 140.
[14] Bessemer, Henry, An Autobiography (London, 1905), ch. xii.
[15] Spring, L. W., "The Story of Iron and Steel" in Kaempffert, W., ed., A Popular History of American Invention, 2 vols. (New York, 1924), vol. II, p. 21.
[16] O'Connor, Harvey, Steel Dictator (New York, 1935), p. 126–29.

to take up the development of an original idea. With the market closely controlled and certain of profits by developing standard methods, those who control our trusts do not want the bother of developing anything new.[17]

It is not that German industrialists were invariably responsive to innovation, for when, about 1880, a Canadian metallurgist suggested the use of iron-nickel alloys for guns, Krupp rejected the idea.[18] In 1916, a committee on foundry methods of the National Founders' Association estimated that not more than 25 percent of the foundries of North America had installed available mechanical appliances.[19]

Great Britain is also faced with the problem of lag in the steel industry. The Committee on Industry and Trade reported: "In the efficiency of its coking plant and in the organization of the coking industry, Great Britain still undoubtedly lags behind the United States and the continent of Europe * * *. In the main the older ovens have been retained, and it is said that there are few plants that have been scrapped altogether since 1906. The explanation given by the representatives of the coke oven owners is broadly that it does not pay to install new ovens in this country in view of their relatively high capital cost * * * the financial condition has made it difficult to raise new capital for replacements and extensions." [20]

In the United States monopoly control retards, for instance, the development of the aluminum industry. Production of aluminum was originally so costly that Deville and Bunsen regarded its use as impractical, but the process of obtaining metal by electrical reduction cheapened its production drastically. The Aluminum Co. of America obtained its monopolistic position by the purchase of this process patent for producing aluminum, issued to Charles M. Hall in 1889, and augmented it later by the purchase in 1903 of a conflicting and competing patent issued to Charles S. Bradley. In 1937, the United States Attorney General's office charged that "By virtue of its 100 percent monopoly of the production and sale of alumina and virgin aluminum in the United States, Aluminum Co. has acquired and is maintaining a monopolistic control of the production and sale of alumina, aluminum, aluminum sheet, alloy sheet, basic fabricated products, and through them of products manufactured therefrom, sold in interstate and foreign commerce, and possesses the power to fix arbitrary, discriminatory, and unreasonable prices and to extend and perpetually maintain said monopolistic control and to exclude others who would, except for said monopolistic control, engage in competition with Aluminum Co. in the production and sale of bauxite, alumina, virgin aluminum, and aluminum products manufactured therefrom. Because new enterprises desiring to engage in the aluminum industry would be placed at the mercy of a single powerful corporation controlling essential raw materials, and because of the great hazard necessarily involved in venturing into a business so completely monopolized by Aluminum Co. and its wholly owned subsidiaries, said monopolistic control has had and will continue to have the direct and immediate effect of suppressing and preventing substantial competition which would otherwise arise in the production and sale in interstate and foreign commerce of bauxite, alumina, aluminum, and aluminum products manufactured therefrom, and is inimical to the public interest * * *." Retardation in the development of the aluminum industry due to monopoly control is detrimental to many fields of industrial growth, particularly because of the importance of aluminum in the development of alloys.[20a]

Textile Machinery

The textile industry was the first battleground of machine technology against hand tools. The beginnings of the conflict developed as early as the thirteenth and fourteenth centuries on the Continent, and for three centuries guild and local authorities frequently ordered new machines destroyed and their inventors imprisoned. In 1397, for example, the tailors of Cologne were forbidden to use a machine for pressing the head of pins. In 1272 Borghesano's automatic machine, run by a water wheel, for twisting silk thread, was used in Bologna. Its secret appears to have been maintained through fear of the death penalty, so that it did not become known in Switzerland until 1555 and in England until 1718.[21] It is reported that about 1579 the Council of Danzig had had strangled the inventor of a machine which would weave four to six pieces at once, lest his invention reduce many workers to beggary. Rev. William Lee, who, in 1589, invented the first knitting machine, the so-called "stocking frame", was refused a patent of monopoly by Queen Elizabeth and James I. He then accepted an invitation from King Henry IV of France, and went to Rouen in Normandy with several looms, only to have

[17] Brandeis, L. D., Other People's Money (New York, 1914), p. 150–151.

[18] Wadhams, A. J., "The Story of the Nickel Industry" in Metals and Alloys, vol. ii (1931), p. 168.

[19] Stecker, M. L., "The Founders, the Moulders, and the Moulding Machine" in Quarterly Journal of Economics, vol. xxxii (1917–18), 281 n.

[20] Great Britain, Committee on Industry and Trade, Survey of Industries, 4 vols. (London, 1927–28), vol. iv, p. 25–27.

[20a] *United States of America* v. *Aluminum Co. of America et al.*, petition filed Apr. 23, 1937, in the District Court of the United States for the Southern District of New York, Equity No. 85–73, p. 21–22. See also "Aluminum Co. of America", Hearings before the Committee on the Judiciary, U. S. Senate, 69th Cong., 1st sess. (Washington, D. C., 1926); and Federal Trade Commission, Report on the House Furnishings Industry, vol. iii (Washington, 1925), ch. iv.

[21] Corey, Lewis, "Machines and Tools" in Encyclopaedia of The Social Sciences, vol. x (New York, 1933), p. 19.

his inventions unrealized because of the king's assassination. The manufacture of looms made by Giambattista Carli of Gemona was ordered discontinued in consequence of the poverty of Venetian stocking-knitters. In England, it was not until 1696 that looms were common, and then their exportation was forbidden in order to keep the improvements secret. In Leyden about 1621 magistrates interdicted the use of a weaving machine because of protests of workers. In numerous parts of Germany, in the late seventeenth and early eighteenth centuries, the ribbon-loom was prohibited, and it was sometimes publicly burned. It was not until 1765 that the electorate of Saxony permitted the use of the looms.[22]

Kay's flying shuttle or "spring loom", invented in 1733, was not in general use in England for cotton weaving until 1760, and its utilization in the woolen and worsted industries, while common in Gloucestershire and parts of Wiltshire by 1803, still caused disturbances in Somerset as late as 1822. Blackburn spinsters in 1768 invaded Hargreave's home and destroyed his spinning jennies which first operated 8, and before long 100, spindles. Workers protested by demonstrating against the jenny when it was first introduced in the South-West clothing district in 1776 and petitioned the House of Commons to abolish the use of the jenny lest it "tend greatly to the Damage and Ruin of many thousands of the industrious Poor." The objection to the spinning jenny symbolized the resistance to the factory system. "Spinning houses" had been organized by the clothiers on their own premises, and weavers feared that they too would be obliged to work under their employers' roofs. A scribbling mill at Bradford, Wilts., was burned down about 1790.

Beginning in Lancashire in 1776, and especially in 1779, there was a systematic attack throughout England on the use of new machines invented by Arkwright, which used water and horsepower for carding, roving, and spinning, and which forced spinning out of the cottage into the factory. In their petition to Parliament in 1780, the cotton spinners of Lancashire described the threat of total loss of employment which made the patent machines "a Domestic Evil of very great Magnitude." They declared that the worker's plight was so "intolerable as to reduce them to Despair, and many thousands assembled in different Parts to destroy the *Causes of their Distress*." They gave evidence that the work produced by the machines was inferior to hand work, and called the machines a mere monopoly "for the immense Profits and Advantages of the Patentees and Proprietors." After the parliamentary committee reported in favor of the new machinery, they again showed the larger social significance of the conflict by their complaint that "the Jennys are in the Hands of the Poor and the Patent Machines are generally in the Hands of the Rich." It is this monopolistic character of Arkwright's inventions that led to wide public sympathy with the workers' attempt to check their use. Arkwright was exceedingly unpopular with other manufacturers because he kept his inventions secret. The landed class not only resented the inventions as facilitating the growing power of the industrialists, but feared that the poor rates would be increased by the burden of persons, whom the machines threw out of work.[23]

The introduction of textile machinery continued to be opposed into the next century. When Cartwright argued that weaving should be done by machinery, experts derided him. His power loom, invented in 1785, Heaton declares to have been in fact almost worthless in its original form.[24] The introduction of weaving machinery was responsible for what has become known as the Nottingham Luddite riots of 1811–12, during which framework knitters sought to break all frames that were being used to make "cut-ups"—that is, pieces which could be cut up into gloves, socks, sandals, and stockings of an inferior kind—and the machines of manufacturers that failed to pay wages agreed upon. In Yorkshire a small band of highly organized and skilled workmen in the woolen industry sought to destroy the gig mills and shearing frames.[25] In France, Jacquard's looms for the weaving of brocaded silks, invented in 1801, were destroyed by displaced workers. The inventor lamented, "The iron was sold for iron, the wood for wood, and I, its inventor, was delivered up to public ignominy."[26]

Opposition to power-driven machinery flared when steam, used in 1785 for the first time in a cotton mill, began to be installed widely. In 1793 "respectable residents" at Bradford, England, protested successfully against the use of the steam engine in worsted mills as "a smoky nuisance" by threatening the proprietor with legal proceedings.[27] Strenuous resistance to the use of steam looms for cotton weaving arose at Lancashire.[28]

As new machinery, which allowed for increased production was invented in the textile industry, it

[22] Beckman, op. cit. vol. ii, p. 371–375, 528–531; Marx, Karl, Das Kapital, 3 vols. (4th ed. Hamburg, 1890), vol. I, tr. by E. and C. Paul (London, 1928), p. 457–458.

[23] Hammond, J. L., and Barbara, The Skilled Labourer, 1760–1832 (London, 1919), p. 49, 160, 53–56, 145–146, 149.

[24] Heaton, H., Industrial Revolution in Encyclopaedia of the Social Sciences, vol. viii (1932), p. 7.

[25] Hammond, op cit. p. 257–260, 301–302, 171–174.

[26] Yeats, op. cit. p. 276.

[27] Hammond, op. cit. p. 153.

[28] Hammond, Rise of Modern Industry, p. 107.

met the opposition of the executives of the industry, who feared that overproduction would disturb existing price levels, and who hesitated to scrap the older machinery until it was worn out physically.[29] They likewise invariably aroused workers' hostility because of the dread of technological unemployment, the initial difficulties of adapting themselves to the new machinery, and the lowered wages and greater speed-up that usually accompanied their introduction.

Competition between various textile products sometimes impedes innovation, as is strikingly shown in the case of the campaign against rayon by the silk manufacturers. When rayon was first put on the market, a committee appointed by silk manufacturers to study its possibilities declared it a transient fad. When it proved to be otherwise, large sums were spent in advertising to discredit the new product.

Sewing machine.—The first sewing machines were regarded either with indifference, amused curiosity, and skepticism as to their utility, or with hostility as to their effects on the livelihood of workers in the needle trades. The machine invented by Thomas Saint in 1790 was viewed as a mechanical toy. In 1832 Walter Hunter's machine was withdrawn by the promoter, George A. Arrowsmith, on the grounds that the introduction of the machine would be injurious to the interests of the hand-sewers. The army uniform factory of Bartholomey Thimmonier in Paris, in which there were 80 of the sewing machines that he had invented in 1830, was destroyed in 1841 by workers who feared for their livelihood, and in 1848 his second factory was likewise destroyed. His machine was never widely used in France and when it was shown at the Crystal Palace Exhibition in London in 1851, no notice was taken of it in the English press. The resistance to the sewing machine patented by Elias Howe in the United States in 1846 was not primarily on account of its displacement of hand workers, although his machine sewed more rapidly than five of the swiftest needle workers. The chief reasons were that it was very expensive, costing $200 to $300 to build, that it could sew only a straight seam, and that break-downs were frequent.[30] After the machine was improved by A. B. Wilson and mass production methods were introduced by Isaac Singer, patent controversies delayed progress. In 1856 the leading manufacturers pooled their patents, and by their control of these basic patents, suppressed any variants that would disturb the market.[31]

The introduction of electric sewing machines was delayed long after they had been devised because they would depreciate the value of the hand- and foot-power machines. Consumers, moreover, hesitated to purchase new models in spite of their undoubted superiority, because of costs, and because the previous machines gave sufficient satisfaction not to make substitution imperative.

Agricultural Machinery

There has been strong consistent opposition to changes in technology in agriculture. The opposition of farmers to the cast-iron plow has already been mentioned. When Jethro Tull sought to introduce mechanical planting of grain by drilling machines to displace broadcast sowing by hand, he was by threats of violence forced to leave many English farm villages.[32] Amos Bronson Alcott would not allow his land to be manured because he considered it "a base and corrupting mode of forcing nature."[33] Whitney's cotton gin was not accepted at once, not only because of the rumor which had its source in Manchester, that the gin injured the cotton fiber, but because of the excessive levy which Whitney and his partner Miller, imposed on the planters who used it.[34] The Hammonds write of the destruction of the threshing machines in England in 1830: "Threshing was one of the few kinds of work left that provided the laborer with a means of existence above the starvation level. * * * It is easy to imagine what the sight of one of these hated engines meant to a parish; the 15 men, their wives and families would have found cold comfort, when they become submerged in the morass of parish relief, in the reflection that the new machine extracted for their masters' and the public benefit 10 percent more corn than they could hammer out by their free hands.[35] James Buchanan's wind stacker was opposed in the 1880's on the grounds that it would pull the grain out of the pipe or shoe with the straw, and that it would use too much power.[36] Ownership of the Buchanan patents on wind stackers later enabled the Indiana Manufacturing Co. to control the introduction of improvements and to suppress those that disturbed the market.[37]

Small-town bankers and businessmen refused for many years to lend money on tractors on the grounds that they were a menace to farmers. They argued not only that farmers could not operate the machine profit-

[29] Jerome, Harry, Mechanization in Industry. National Bureau of Economic Research, Inc., Publication, no. 27 (New York, 1934), p. 333.

[30] Lewton, F. L., "The Servant in the House: A Brief History of the Sewing Machine" in Smithsonian Institution, Annual Report, 1929 (1930), pp. 559–583.

[31] Vaughan, op. cit., p. 36.

[32] Horine, M. C., "Farming by Machine" in Kaempffert, W., ed., A Popular History of American Invention, 2 vols. (New York, 1924), vol. ii, pp. 256–257.

[33] Seldes, Gilbert, The Stammering Century (New York, 1928), p. 208.

[34] Iles, op. cit., pp. 82–83.

[35] Hammond, J. L., and Barbara, The Village Labourer, 1760–1832 (London, 1911), 220–221.

[36] Horine, op. cit., p. 297.

[37] Vaughan, op. cit., p. 46.

ably, but also that if they were successful, the farmer would have too much leisure time. They had investments in horses and foresaw their eventual decline in price if tractors were utilized. The national horse associations led in circulating propaganda against tractors and were joined by the local bankers. Farmers were easily susceptible to such a campaign for the price of tractors was high, horse-drawn implements became almost a total loss, and the farmers were often sentimentally attached to their horses. Farmers rarely had sufficient evidence one way or the other on the question whether the breakage on the tractor and the amount of fuel required were excessive. The opposition of the farm wage workers, displaced by the tractor, was also great.

Delay in the effective utilization of tractors is in many countries and regions due to the system of land ownership prevailing, for in order to be exploited profitably, tractors require vast concentration of land areas, as in western United States and in the collective farms of the Soviet Union. Any trend toward smaller holdings as is advocated widely in the United States and especially in Fascist countries tends to negate and make impossible the application of modern agricultural technology.

Fear of overproduction of cotton with consequent shattering of existing price levels, and of drastic displacement of cotton pickers, is deterring the introduction of the automatic cotton picker invented by the Rust brothers. According to the estimate of the Delta Experiment Station of Stoneville, Tenn., the Rust machine, which can pick in 7½ hours as much as a good hand picker can pick in 5 weeks, will displace over 75 percent of the labor population in the southern cotton country if the invention is thrown upon the market in the regular manner. The inventors, cognizant of the revolutionary consequences attending their invention, are themselves withholding its application, except for its trial use on a cooperative farm in Mississippi and in the Soviet Union, where the problem of unemployment does not exist and the introduction of the machine can be regulated.

In general, a situation such as exists in capitalist countries where food production is being curtailed in the interest of price maintenance for profit is hardly conducive to the introduction of improvements in agricultural technology. In fact, retrogression has been apparent, with technologies already introduced being abandoned, particularly during the depression.

Building

Architecture has always been conservative. When the early dwellers on the Alpine lakes descended into the Italian plains, they continued to build pile dwellings, even when they settled on hilltops.[38] It took 350 years and 13 kings to eliminate inflammable straw roofs from Danish towns.[39] In spite of their extreme combustibility and the inadequate protection from the cold that they afforded, and the easy availability of timber which was cheaper and better, thatched cottages survived for a long period in the American colonies.[40] Churches and public buildings still cling to ancient and medieval forms. There was long delay in using iron in building, and when it was used it was either hidden, or when unavoidably shown, employed with no idea of its aesthetic possibilities. When Buffington took out patents for the steel-frame skyscraper in 1888, the Architectural News predicted that the expansion and contraction of iron would crack all the plaster, eventually leaving only the shell.[41]

The pressure of vested interests has been a decisive factor in retarding change in housing materials. The lumber companies long fought legislation prohibiting the building of inflammable wooden buildings in large cities.[41a] Wooden shingle companies lobbied against laws for fireproof roofing.[41b] Brick manufacturers carried on a persistent campaign for years against concrete structures, predicting their collapse.

Central heating systems have met stubborn and persistent opposition. In England particularly, advances in heating methods have been widely ignored.

Adequate toilet facilities, still regarded as incidental luxuries by many builders of homes for workers, were only slowly introduced into the homes of the middle-class late in the nineteenth century. Earlier the bathroom was regarded as a superfluity in the palace of Versailles, and the bathtub was removed and put in the garden for a fountain.[42] There is ample evidence that inhabitants of the palace acted in the spirit of Philip of Spain, who had authorized the destruction of all public baths left by the Moors on the grounds that washing the body was a heathen custom dangerous to believers.[43] In the 1840's the bathtub was denounced in the United States as an epicurean innovation from England designed to corrupt the democratic simplicity of the Republic. The medical profession warned against it as a producer of rheumatic fevers, inflam-

[38] Giuffrida-Ruggeri, V., A Sketch of the Anthropology of Italy, in Royal Anthropological Institute of Great Britain and Ireland, Journal, vol. xlviii (1918) 99–100.

[39] Lowie, R. H., Are We Civilized? (New York, 1929), pp. 72–73.

[40] Wertenbaker, T. J., The First Americans, 1607–1690 (New York, 1927), pp. 284–285.

[41] Polk, Grace, Sire of the Skyscraper, In New York Times Magazine (New York Nov. 21, 1926), p. 15.

[41a] National Lumber Manufacturer's Association, Highlights of a Decade of Achievement (Washington, D. C., 1929), p. 33–40, 53 55, 62.

[41b] Brief on behalf of the National Lumber Manufacturers Association before the Federal Trade Commission (Washington, D. C., 1916), p. 46, 51.

[42] Boehn and Fischel, op. cit. p. 79–80.

[43] Hogben, Lancelot, Genetic Principles in Medicine and Social Science (London, 1932), p. 213.

matory lungs and all zymotic diseases. Attempts were made to legislate against it. An ordinance prohibiting bathing between November 1 and March 15 failed of passage in the Philadelphia Common Council in 1843 by only two votes. Heavy water rates were levied against those who had bathtubs in Virginia, and a tax of $30 imposed on their possessors in certain towns. When President Filmore installed a bathtub in the White House in 1851, there was an outcry against it as a "monarchical luxury" which could well be dispensed with inasmuch as former Presidents had gotten along without them.[44]

Organized skilled workers in the building trades have slowed down the introduction of processes that threaten to endanger their health, destroy their skill, lower their wages, and cause technological unemployment. Between 1911 and 1921, prohibitions against cutting, measuring, and threading by machine, of iron pipe of specific diameter were incorporated in agreements between plumbers' unions and builders' associations and there were restrictions in regard to the use of substitutes for ferrules and brass soldering devices.[45] Granite cutters resisted the introduction of surfacing machines and of pneumatic hammers which, in addition to speeding up, involved the hazard of silicosis. Painters object to the paint spray which endangers health by benzol poisoning.

When recently the mechanized industries, particularly in metal, entered the housing field with the production of "prefabricated houses", they were met by the resistance of property holders, especially of the banks, who hold mortgages on about 58 percent of 1933 value of all urban real estate,[46] and who fear that an influx of cheap modern dwellings would subtract substantially from the market value of existing structures.[47] These banks and loan companies have been unwilling to finance prefabricated houses except in rare exceptions and then on a limited basis. Lumber companies and manufacturers of other materials which are being displaced in the production of prefabricated houses, have sought to prevent their construction through building-code restrictions and by organizing boycotts by dealers and building crafts. Moral and ethical rationalizations have been used against prefabricated houses. The director of the New England division of the American Institute of Architects in May 1934 attacked prefabricated houses as tending "to substitute a life of vagrancy for responsible citizenship in the community."[48] The author of an article entitled, "Houses Cannot be Built Like Automobiles", who speaks on behalf of architects against prefabrication, argues plaintively, "Spiritual, mental, and physical well-being is enhanced always by the exercise and development of individualism, especially when related to the home and its environment. Housing that fails to respect these human values must be considered among the 'chats' to be discarded."[49]

Planned public housing projects such as slum clearance which afford the most efficient methods of utilizing advanced technologies in the building industry, crash against the wall of vested private-property interests. They meet the combined opposition of the owners of obsolete buildings, that nonetheless are still profitable, of landowners who demand prohibitive prices, of holders of mortgages who fear a depreciation of housing values through the increase in available homes. Achievements in building technology lie sterile in the face of the opposition of these interests. It has been calculated that at the rate of replacement between 1921 and 1933 of homes and apartments, the American house will be in use 142 years.[50] Such slow replacement, based on profits derived from old houses, impedes the building of new structures, however pressing the housing needs for the mass of the population of the United States may be.

2. Psychological and Socio-economic Factors Involved in Resistance to Technological Innovations

Each example of opposition to technological innovation that has here been given has obviously its unique constellation of circumstances and causes. But comparable situations appear frequently enough to permit a tabulation of the basic factors involved in resistance to technological advance. In every case there are both cultural and psychological factors present, related in an inextricable manner, as aspects of the same situation; the cultural gives the historical and socio-economic setting which provoke a specific psychological response from the individuals participating. From the results of this study it is apparent that the psychological factors of habit, fear, desire for personality equilibrium and status, and the tendency of groups to coerce their members to conformity, are latent predisposing factors toward resistance to change. The manner and degree in which these factors function depend on forces in the cultural environment. The most potent of the cultural factors are clearly economic: Efforts to maintain economic advantage and hegemony

[44] New York Times, Nov. 21, 1926. Sec. VIII, 12:1.

[45] Montgomery, R. E., Industrial Relations in the Chicago Building Trades (Chicago, 1927), p. 168.

[46] Clark, Evans, The Internal Debts of the United States (New York, 1933), p. 6.

[47] Lonberg-Holm, K., and Larson, C. T., Trends in Building Production, in Real Estate Record, vol. cxxxvii (Apr. 18, 1936), pp. 19–25.

[48] Pre-Fabrication, in Architect and Engineer, vol. cxvii (May 1934) 73–74.

[49] North, A. T., Houses Cannot Be Built Like Automobiles, in American Architect, vol. cxlii (December 1932), pp. 18–20.

[50] Clark, op. cit. p. 67.

over competing classes, and over competitors in the same industry and rivals for the same market in allied fields; costs of introducing the new method or product, which in its early form is usually crude and unstandardized, and but one of a number of innovations designed to solve the specific problem at hand; the losses incurred through the depreciation of machinery and goods made obsolete by the innovation; the unwieldy structure and the rigidity of large scale corporate enterprises that hesitate to disturb a market which already yields profits through restricted production; the difficulties of small-scale enterprise to make the necessary capital investments; the stultifying influence of capitalist crises; and labor's efforts within a profit system to prevent being victimized by technological unemployment, by loss of skill, by speed-up and lowered wages. There are also political factors that have their own dynamics of functioning which may be directed to impede technological change, as for example the restricting influence of nationalism; faulty patent legislation and judicial decisions justifying suppression; the system of issuing "perpetual" franchises; the power of dominant industrial groups to control legislation to their interests as against beneficial innovations that imperil their profits. There are likewise religious forces that, as a rule, cement the status quo, and buttress resistant attitudes whose roots lie in more materialistic causes.

A classification of causes in this manner tends to be too bare to be of much value, just as the diversity of their functioning in each particular case of resistance to technological change, tends to obscure the common principles involved. For this reason, it is important that a framework of reference be given, by a picture of the psychological roots and the general socio-economic setting of this conservatism.

Men, however variable, are everywhere of one species and for this reason similar psychological factors underlie all human behavior under whatever social institutions men live. Resistance to change is, to this extent, rooted in the individual, just as is its antithesis, receptivity to new experience.

The tendency of an individual to persist in certain forms of set behavior and to select experience in terms of these forms, ignoring or opposing variants, is based in part on what is vaguely called habit, or conditioned response. Although Pavlov and others have shown experimentally the genesis of these conditioned responses, the physiology of retention at the basis of their formation is still little known.[51] Various theories have been proposed. Cason believes that the nature of the retention depends upon the degree of elasticity of the surface membranes of the nervous system, which is determined by their chemical composition.[52] The theory of learning stemming from Sherrington regards the permeability of the synapse as the decisive factor.[53] Kappers holds that permanent connections in the nervous system are established through the growth of dendrites and axones under the influence of bio-electric currents.[54] None of these theories are as yet conclusive; and the problem of the physiological basis of retention as one aspect of conservatism remains for future clarification. It should be recognized, moreover, that there is not necessarily any correlation between specific retention abilities and resistance to change. Conservatism is made possible by neural retention, but excellent retention can be associated with agile flexibility of behavior and attitude, while the archconservative may be weak in his power of retention. Resistant attitudes must be explained largely in terms of the symbolic rather than the neurophysiological level of behavior.

The adjustment of a person to his environment demands that he channelize his behavior to some extent in the interests of personality integration. He cannot be continuously expending his energies and undergoing crises in making decisions. Judgments once made must serve as guiding precedents. A large part of his behavior of necessity becomes quasi-automatic involving little deliberation or judgment. This behavior, oft-repeated, becomes suffused with emotional tones of pleasure, particularly when it involves skillful movements. One's personality becomes relatively at ease when it has attained an element of equilibration with the objects and persons with whom he comes in contact. Personality becomes bound up with environment by sentiments of intimacy. The strength of these attachments vary, depending upon the degree of the stability of the culture in which one lives. Where social forms are more dynamic and transient, the extent of permanency in adjustment is less than in a relatively static society. There is an emotional and aesthetic feeling of happiness derived from identification with the customary forms when these forms provide a minimum of gratification of human wants. Escape mechanisms facilitate a specious sense of adjustment and fantasy creates a world of unreality which obscures actual discomfort particularly when

[51] Pavlov, I. P., Conditioned Reflexes, tr. from the Russian (Leningrad, 1926) by G. V. Anrep (Oxford, 1927); Lectures on Conditioned Reflexes, tr. by W. H. Gantt (New York rev. ed. 1936); and An Attempt at a Physiological Interpretation of Obsessional Neurosis and Paranoia, in Journal of Mental Science, vol. lxxx (1934) 187–97.

[52] Cason, Hulsey, The Physical Basis of the Conditioned Response, in American Journal of Psychology, vol xxxvi (1925) 371–393.

[53] Sherrington, C. S., The Integrative Action of the Nervous System, Yale University, Mrs. Hepsa Ely Silliman Memorial Lectures (New York, 1906).

[54] Kappers, C. U. A., Further Contributions on Neuroblotaxis: IX. An Attempt to Compare the Phenomena of Neuroblotaxis With Other Phenomena of Taxis and Tropism. The Dynamic Polarization of the Neurone, in Journal of Comparative Neurology, vol. xxvii (1916–17) 261–298.

the economics of a society offer no certainty of employment and subsistence to its masses, and these live within the threatening shadow of insecurity.

An innovation, especially one which affects one's economic status as in the case of technologies, rudely shatters whatever equilibrium a person has attained. It demands not only motor reconditioning but reorganization of personality to meet the needs of the new situation. Poise gives way to at least temporary uncertainty. One's place in the new configuration is uncertain. New decisions are demanded. Efforts must be expended; discomforts of readjustment experienced. Life becomes more complex, in that it is less routinized, and appears to teem with hazards.

It is little wonder that an innovation, whatever its nature may be, provokes feelings of impropriety, and repelling defense attitudes of ridicule and disparagement, or is deliberately ignored and thus not permitted to enter experience. No matter how meager the adjustment that has been attained, it is often viewed as superior to the seemingly tempestuous uncertainties involved in reorientation. Unless there are incentives which stimulate conscious effort toward change, rationalizations are used to justify the established behavior by excuses which sanction it. This has been well expressed in the Declaration of Independence: " * * * all experience hath shewn that mankind are more disposed to suffer while evils are sufferable, than to right themselves by abolishing the forms to which they are accustomed."

Resistances involving rationalizations are often made even if only slight changes in behavior are demanded because of the distrust of possible future commitments. But the closer the new approximates the old, the more likely it is to be accepted. Innovations are smuggled in through transitional forms. The earlier forms of an innovation growing out of a specific culture—that is, not coming from without through diffusion—as a rule deviate little from the preceding forms that are being displaced. This happens sometimes by intention, but primarily because of the limitations of innovators, who, like their public, are bound by previous experience. Changes are made detail by detail and not at once, not only because of psychological inertias, but because an invention is circumscribed by existing knowledge and by the tools and materials available. To avoid the acceptance of the new, moreover, old forms of techniques may be reinterpreted or modified slightly, acquire new utility and value, and survive as rivals of the new.

In the absence of unusual incentives, when an innovation is drastically novel, or because of its complicated nature, exacts fatiguing efforts for readjustment, or involves pain, however temporary and slight, resistance is intense and rationalizations flourish. To cling stubbornly to the old forms, however overwhelming the details of their performance may be, is often regarded as preferable to going through the temporarily disturbing process of readjustment.[55]

Deliberation before accepting an innovation is of course commendable, for innovations are not always efficacious, and the hopes of the inventor are often illusory. Inventions, later to prove epoch-making, are sometimes in their initial form very crude, and even inferior to the forms in use. The social significance of many innovations is not realized, a fact well characterized by MacIver's analogy: "Inventions enter the world like new-born babes. Their power to change the modes of life and the thoughts of men does not appear until they are grown up."[56] They often in their early trials prove failures. Furthermore, with innovations crowding upon one another, especially in modern times, when skills and fields of interests are specialized, it is difficult to know, and few are competent to judge, which will prove to be successful. Skepticism thrives on the fact that the annals of invention are crowded with innovations, originally hailed as epoch-making, that have come to naught. A mistake in judgment concerning one innovation leads to excessive caution: "Once bitten; twice shy."

Opposition to innovation is not invariably on a quasi-automatic level. Especially in economic and technological fields, there is involved conscious self-interest in the maintenance of status and, in some cases, even of life itself. Abstract "progress" usually rates insignificantly compared to the actual, immediate effects which an innovation has directly on the person or class involved.

Contemporary education in the United States appears to do little to facilitate or promote receptivity to technological innovation and is rather occupied with the organization and perpetuation of past experience and tradition. The majority of graduates, even of universities, remain ignorant of the relation of technology to contemporary culture, and few technologists are educated outside of the narrow limits of their specialities. With few persons equipped with the experimental or scientific method of verifying data, or accustomed or able to analyze proof as a criteria of truth, there must be recourse to authority. The virtue in such use of authority is counteracted by the fact that in the field of technology experts have been historically conservative, have been indifferent to and have lacked understanding of the social aspects of their work, and have often been too biased in terms of

[55] Stern, Bernhard J., Social Factors in Medical Progress (New York, 1927), pp. 1–19.

[56] MacIver, R. M., "Civilization versus Culture", in University of Toronto Quarterly, vol. i (1931–32) 316–32.

their own schooling and specific research to give deliberate and reasoned judgments.

There are factors involved in resistance to change that are implicit in group behavior. The collective behavior of groups is expedited by orderliness based on the ability to anticipate the behavior of their members. Innovations are disruptive in that they affect not isolated persons but members of groups who influence the behavior of all with whom they come in contact. There is in consequence group resentment against innovators because they disturb established relations, upset routines, and cause temporary confusion. Social pressure upon the deviant to conform follows. Caviling criticism, ridicule and disparagement, economic discrimination, social ostracism, and violence are utilized. In order to avoid such reprisals most persons endorse customary procedures and refrain from projecting or supporting innovations. Social approval gives the tone to personal adjustment, and the restraints imposed by group attitudes are thus powerful deterrents of change. The size of the community is a factor in determining the strength of its power of coercion. If it has many members, cohesion is not as close, and the innovator, finding some support, may be able to ignore detractors, but in a small community, contacts are more immediate and the influence tends to be more direct. The deterrent of group criticism functions not only in the general group life of the community, but within specific industrial organizations. To avoid the unpleasant, an individual tends to continue established routines rather than to venture with revolutionary innovations that will meet the resistance of his co-workers and superiors. "Not to venture, is not to lose", becomes a guiding principle unless incentives are strong.

In different cultures, opposition to technological change has varied in its character and strength. The factors inhibiting innovation in primitive societies, apply to a large extent to small isolated communities throughout history, and to rural communities in the modern world. Absence of a knowledge of writing in preliterate societies, and illiteracy in civilized societies, establish the need of conserving tradition through speech and behavior. Sparcity of the technological base, a relatively scant margin of safety and wealth which permits few risks, the conformity demanded within closely related groups, little division of labor which diminishes the possibilities of experimentation, dominantly nonempirical attitudes, isolation which limits horizons and experience and permits few collisions with novel concepts from without, and close integration of different aspects of the cultural configuration—all intensify conservatism.

In the ancient world, technological advances such as Hero's steam engine and mechanical appliances for construction work, were neglected mainly because of the abundance of the labor supply, because of the belief that it was degrading to science to put it to practical uses, and because of the disparaging social attitude toward artisans and manual labor.

The cultural retrogression of the Middle Ages in Europe, which made the situation prevailing in many medieval communities approximate in some respects that of primitive societies, was not conducive to innovation, least of all in the field of technology. The hierarchic social stratification that was sanctioned as divinely ordained by the Church, which spiritualized poverty and denounced materialism and experimentation, created an economic setting and authoritarian attitudes fatal to scientific progress and technological change. Medieval society was not entirely immobile and unprogressive. But local self-subsistence was a limiting economic frame, and the anti-scientific attitude of the Church enforced by heresy trials afforded an environment hostile to scientific and technological innovations.

The revival of interest in classical science, slowly followed by the beginnings of the experimental methods; the discovery of new continents, the plunder of which brought vast new wealth to Europe; the rise of cities with consequent increasing power of the burghers formed the social setting of capitalism that accelerated change and led the way to increasing receptivity to technological progress. Delays were now occasioned not only by efforts of the aristocracy to check the rise of the industrial bourgeoisie, but factors, peculiar to the structure and functioning of capitalism, impeded technological advance.

Under capitalism, the almost exclusive incentive to the incorporation of technological improvements into industry has been the drive for profits. The profit motive undoubtedly served as a ferment, accelerating change, in the early days of capitalism in contrast to a relatively static feudal economy. Its effectiveness in this respect was and is dependent upon the availability of markets, and the need to acquire or maintain control of that market in competition with rival capitalists. When new continents were being opened as markets, and capitalism was an expanding economy, new machinery could more readily be used to supplement the old. Competition between entrepreneurs, although it led to wasteful anarchic production and marketing, to some extent stimulated a response to technological innovation to keep ahead of competitors. But in the degree to which monopoly in the setting of the profit system is able to control prices, standardize products, and restrict production, alertness to technological change is diminished, a brake is put on inventions and their applications.

William M. Grosvenor has, in Chemical Markets, expressed the sentiments of modern corporate management toward the utilization of new inventions:

> I have even seen the lines of progress that were most promising for the public benefit, wholly neglected or positively forbidden just because they might revolutionize the industry. We have no right to expect a corporation to cut its own throat from purely elemosynary motives * * *. Why should a corporation spend its earnings and deprive its stockholders of dividends to develop something that will upset its own market or junk all its present equipment * * * when development is directed by trained and experienced men responsible to stockholders for expenditures, they have little inducement to try to supersede that which they are paid to develop and improve.[57]

Harry Jerome, after a study of mechanization of industry under the auspices of the National Bureau of Economic Research, likewise formulated the principle that guides the relation of present-day capitalism to technological progress:

> Technical progress far outruns actual practice. This margin of nonuse is in part due to nonpecuniary factors, but the major explanation is simply that, on the whole, industry must be conducted with profits as the immediate goal; hence the first and major consideration in any choice of method is not merely, Will it do the work? but also Will it pay?[58]

The results upon technological invention of excessive rigidity of monopolistic enterprise, arising from its fear of imperiling its heavy investments, especially in durable goods, and from its elaborate mechanics of functioning, was noted before the Oldfield Hearings on Patents in 1912, by Louis D. Brandeis:

> These great organizations are constitutionally unprogressive. They will not take on the big thing. Take the gas companies of this country; they would not touch the electric light. Take the telegraph company, the Western Union Telegraph Co., they would not touch the telephone. Neither the telephone company nor the telegraph company would touch wireless telegraphy. Now, you would have supposed that in each one of these instances those concerns if they had the ordinary progressiveness of Americans would have said at once, "We ought to go forward and develop this." But they turned it down, and it was necessary in each one of those instances, in order to promote those great and revolutionizing inventions, to take entirely new capital.[59]

Charles F. Kettering, vice president and director of research of the General Motors Corporations, likewise stated in this connection in 1927:

> Bankers regard research as most dangerous and a thing that makes banking hazardous, due to the rapid changes it brings about in industry * * *[60]

Monopolies are themselves not only irresponsive to change, but through their control of basic patents and improvements, and also of kindred patents, only a few of which they utilize or develop, they prevent others from making technological changes in the fields which they preempt. Such is the testimony of the Inventors' Guild:

> It is a well-known fact that modern trade combinations tend strongly toward constancy of processes and products, and by their very nature are opposed to new processes and new products originated by independent inventors, and hence tend to restrain competition in the development and sale of patents and patent rights; and consequently tend to discourage independent inventive thought.[61]

Judicial decisions in United States courts have sanctioned the suppression of patents in decisions which are of primary importance when resistance to technological change in the United States is being appraised. In 1896 the judgment of the court was that the patentee "may reserve to himself the exclusive use of his invention or discovery * * *. His title is exclusive, and so clearly with the constitutional provisions in respect of private property that he is neither bound to use his discovery himself, nor permit others to use it." When this decision was reaffirmed in 1909, it was declared that "the public has no right to compel the use of patented devices or of unpatented devices when that is inconsistent with fundamental rules of property."[62] Technological progress is thus inextricably made dependent upon property rights interpreted in terms of individual rights and the rights of a specific industry as against the interests of the community. In practice, this interpretation benefits large corporations. For it is the consistent experience of inventors that they are helpless to promote their patents independently in fields which are dominated by such corporations. A chief obstacle is, of course, lack of capital to put their plans in operation.[63] They find themselves involved in costly infringement suits, and harassed by interference procedures, which oblige them to sell their patents to the large-scale enterprises with concentrated capital resources, and in this way take a chance at their suppression. Patent pools often keep the benefit of patents within a small circle of corporations and restrain independents from their use, thus preventing broad technological advance. The rule of monopolies in technological change suggests at once an analogy with the restraining influence of the medieval guilds.

It is often argued that the establishment of laboratories and research associations by large corporations and cartels disproves the charge of inflexibility of giant industry. But these relatively few research de-

[57] Grosvenor, W. M., The Seeds of Progress, in Chemical Markets, vol. xxiv (1929) 23–26.

[58] Jerome, op. cit. p. 33.

[59] U. S. Congress, House, Committee on Patents, Oldfield Revision and Codification of the Patent Statutes: Hearings, 62d Cong., 2d sess. (1912) no. 18, p. 12.

[60] Address before Association of National Advertisers, in Detroit, May 9, 1927.

[61] Vaughan, op. cit. p. 212.

[62] Vaughan, op. cit. p. 161, 164.

[63] Rossman, Joseph, The Psychology of the Inventor (Washington, 1931), pp. 161–162; Wyman, W. I., Patents for Scientific Discoveries, in Patent Office Society Journal, vol. xi (1929), p. 552.

partments give the corporations greater control over the innovations that might disturb the market. According to Grosvenor, only 12 out of the 75 most important inventions made between 1889 and 1929 were products of corporations' research.[64] Evidence that inventions under these auspices are not fully utilized is given in the British Report of the Committee on Industry and Trade, made in 1929, by Sir Arthur Balfour:

> It is when we come to consider the relation between the research associations and the industries themselves, and the extent to which these industries avail themselves in practice of the results of research by their own associations, that we find most cause for disquietude * * *. We have laid special stress on the importance of this aspect of the question of scientific research in relation to industry, because, in our opinion, it is the imperfect receptivity toward scientific ideas on the part of British industry which is at the moment the main obstacle to advance.[65]

The dominance of profit over these research activities is seen in the drastic retrenchment in research staffs concomitant with the economic crisis.

While in its early periods capitalism was more responsive to advance in technology, there have always been within it, forces which have checked maximum receptivity to technological innovations. Factors inherent in the structure of capitalism have often made technological innovation overwhelmingly, and sometimes exclusively, in the interests of a relatively few owners of industry, and to the disadvantage, sometimes temporary, but often permanent, to the masses of the population. The technical innovations in the early phases of the industrial revolution were introduced with callous disregard of the havoc they wrought in the lives of the skilled artisans, as have such changes, with few exceptions, since. They have in fact been utilized repeatedly to curb the militance of labor. Andrew Ure acknowledged this already in 1835 when he called the invention of the self-acting mule "a creation destined to restore order among the industrious classes * * *" and added "This invention confirms the great doctrine already propounded, that when capital enlists science in her service the refractory hand of labor will always be taught docility."[66] James Nasmyth is quoted to have declared that the desire to break strikes was a prime factor in the introduction of machinery:

> In the case of many of our most potent self-acting tools and machines, manufacturers could not be induced to adopt them until compelled to do so by strikes. This was the case with the self-acting mule, the wool-combing machine, the planing machine, the slotting machine, Nasmyths steam-arm and many others.[67]

Workers can hardly be expected to be receptive to technological changes in the specific fields in which they are employed, when they are cognizant that their skills will be rendered worthless and their status imperiled by resulting unemployment. It is opposition so motivated that has sometimes reached dramatic proportions, in many industries, particularly in the textile, mining, iron and steel, shoe, machinery, clothing, railroad, cigar, and glass industries.

The degree of trade-union or class consciousness determines the extent to which workers in a situation of technological change understand, articulate, and act upon their resentment at being the victims of such change. It also decides the form which their expression takes. Among unorganized workers, action is often directed against the machine itself as the immediate cause of their degradation, with the result that machine wrecking occurs. Trade-unions reject the tactic of destroying machinery and seek to substitute organized measures of bargaining with employers to lessen the impact of the tragedy of displacement through the more gradual introduction of the machine or process, and by demands for compensation to those displaced. Socialists and communists likewise discourage wrecking of machinery, support trade-union methods to get as much for the workers involved as is possible in a given situation, advocate social insurance programs to take care of the unemployed, as do many trade-unionists, and at the same time seek to crystallize resentment in preparation for a seizure by power by labor to establish an economy in which technology will not be subject to the exigencies of a profit system but may be used to the fullest in the interests of the entire population.

The failure of industry to keep abreast of technique is due in part to the periodic crises in capitalist economy. Even in periods of the upward swing of the cycle there is always the inhibiting fear of introducing technological changes that will cause overproduction and accelerate another crisis. Inasmuch as attempts at planning under capitalism have been directed toward restricting production, they have acted as curbs upon technological innovation. In the midst of a crisis, with available machinery working at but a fraction of its capacity, few new inventions are utilized except for the purpose of lowering labor costs. In 1932, for example, purchases of industrial machinery in the United States are reported to have declined 74

[64] Grosvenor, op. cit. p. 24

[65] Great Britain, Committee on Industry and Trade, Final Report, Com. 3282 (London, 1929), pp. 215, 218

[66] Ure, Andrew, The Philosophy of Manufactures (London, 1835), pp. 367–368.

[67] Smiles, Samuel, Industrial Biography (new ed. London, 1876), pp. 294–295.

percent under the annual average for 1919–29.[68] In hearings before the House Committee on Patents in 1932, Representative Hatton W. Sumners of Texas argued that the Patent Office should cease granting patents on labor-saving devices because of unemployment.[69] Efforts were made to restrict productive capacity and thus to maintain or raise prices under the N. R. A. The Research and Planning Division of the N. R. A. reported in February 1935, that all construction was restricted by code provisions in the following industries: Cordage and twine, petroleum, glass container, excelsior, American glassware, crushed stone, structural clay, roofing tile, drain tile, China clay, floor tile, alloys, iron and steel, carbon black, pyrotechnics, candle, tool and implement, and ice. Ten of these codes merely stipulated that no construction be made without authorization of the code authorities, and six permitted "modernization." Code amendments also restricted construction in the cotton textile and lace manufacturing industries.[70] On the other hand, the raising of wage levels led many employers to substitute machinery for labor, and to rationalize their plants, so that the influence of the N. R. A. in discouraging technological change varied in different industries.[71]

In public works and in private industry, there have been moreover in times of crisis definite evidences of retrogression in technology. Advocacy of the return to earlier mechanical processes in public works derives from an attempt to solve the problem of unemployment. The Engineering News Record of December 11, 1930, declares replacement of machines by hand labor to be:

> a burning question with many city engineers and administrative officials. Some have already answered it in favor of hand labor. * * * Minneapolis is planning to use pick-and-shovel men instead of machinery in its winter program of municipal improvements. Boston proposes to abolish the use of snow-loading machines in clearing its streets after a snowfall. Newark has just begun hand excavation in converting the abandoned Morris Canal to a subway roadbed. Akron and Sacramento have put the pick-and-shovel plan into practice. * * * And so the list goes.[72]

In private industry the shrinking of the markets which favored mass-production methods has necessitated in some cases the abandonment of the technologies at the basis of such methods and the return to machinery which produces more economically for a local market. Albert Kelsey, technical adviser to the Pan American Union, reported in 1931 that several South American countries were contemplating steps to abolish machine work and to substitute hand labor, that Bolivia had practically penalized the use of machines in mining, and that Chile was considering the abolition of motor trucks.[73]

A return to small-scale production methods in industry and agriculture cannot help but curtail technological progress at this period of history. Scientific research upon which modern technological invention is based has too many ramifications and is too costly to be undertaken and financed by small producers. Inevitably, existing technology, which is the primary contribution of the western world to civilization, could not be maintained; its continuance has already met strenuous opposition wherever the theory or practice of small-scale production is current.[74]

Retrogression has been justified and even commended in antimachine polemics such as those of Spengler who writes: "The flight of the born leaders from the machine is beginning." Comparable sentiments are expressed in the works of publicists attached to agrarian movements such as the Southern Agrarians in the United States.[75] In most of this literature love of the past degenerates into a flight from the present; and the Middle Ages has been idealized as an escape from the depressing conditions of a capitalist crisis. Nineteenth century movements for the revival of handicrafts, such as that led by William Morris, were similarly backward looking in their implications. They were not motivated, however, by aristocratic revulsion to the machine as invading the prerogatives of a landlord class, as are primarily the social philosophies of Spengler in Germany, and comparable publicists in England, and in the United States, but rather by sympathy for the plight of machine workers and esthetic dissatisfaction with the ugly products of early machine production. Gandhi's attempt to prevent the displacement of handicraft by machine economy is due to his identification of machine technology with British imperialism. In most countries there have been requests for "scientific holidays" and a "mora-

[68] Industry is Thirty Billion Dollars Behind on New Equipment Purchases and Industry Needs Modernization but Awaits Low-Cost Capital in Business Week, no. 154 (1932) 20–21; no. 155 (1932) 14–16.

[69] Sumners, H. W., in U. S. Congress, House, Committee on Patents, Patents: Hearing on General Revision of Patent Laws, 72d Cong., 1st sess. (1932), pp. 39–46.

[70] U. S. National Recovery Administration, Research and Planning Division, Report on the Operation of the National Industrial Recovery Act (Washington 1935), p. 53.

[71] Strachey, John, The Two Wings of the Blue Eagle, in Nation, vol. cxxxvii (1934), 42–43; Lyon, L. S., and others, The National Recovery Administration, Brookings Institution, the Institute of Economics, Publication No. lx (Washington 1935); Standard Statistics Co., Inc., Standard Trade and Securities, vol. lxxi, no. 2, sec. 1 (Jan. 3, 1934), p. M5—M8, vol. lxxxvi, no. 35, sec. 3 (June 19, 1935), PMA–9—MA–11.

[72] Schmitt, F. E., Hand Against Machine Work in Engineering News-Record, vol. cv (1930), 915.

[73] New York Times, Dec. 29, 1931, p. 7.

[74] The Frustration of Science, by Sir Daniel Hale, J. G. Crowther, J. D. Bernal, and others (London 1935); Rubinstein, M. I., Science, Technology, and Economics under Capitalism and in the Soviet Union (Moscow 1932).

[75] Spengler, Oswald, Der Mensch und die Technik (Munich 1931), tr. by C. F. Atkinson as Man and Technics (New York 1932). Agar, Herbert, and Tate, Allen, eds., Who Owns America? (Boston, 1936).

torium on inventions", which have found echo in business and scientific circles. Such climate of opinion is hardly healthy for technological advance. On the other hand, in the Soviet Union technological progress is being fostered as a means of achieving the governmental objective of a socialist, planned, large-scale economy for the satisfaction of expanding consumers' needs.[76]

In summary, resistance to technological change has been so much a part of the texture of the historical process, that it cannot be ignored when the future of technology is charted. There are psychological factors in individual and group behavior which predispose toward inertia in receptivity to innovation, but these may be counterbalanced by potent incentives that promise material and nonmaterial rewards. The basic determinants of the presence or absence of impediments to technological change lie therefore in the nature of the social, and primarily the economic, structure of a society, in the degree to which it offers incentives to the masses of the population and in the manner in which these can be realized through a planned economy. Capitalism has inherent in its structure and functioning, factors which militate against such realization, and thus prevent industrial practice from keeping apace with scientific knowledge.

[76] Webb, Sidney and Beatrice, Soviet Communism: A New Civilization (New York 1936), pp. 767–71; Moore, Harriet, The Stakhanov Movement in American Russian Institute, Research Bulletin, vol. I, no. 2 (New York 1936).

V. UNEMPLOYMENT AND INCREASING PRODUCTIVITY

By David Weintraub [1]

Introduction

The economic literature of the past two centuries is interspersed with debates concerning the effects of the increasing use of machinery on the volume of employment. The introduction in the eighteenth and nineteenth centuries of the early forerunners of our modern machinery was in many instances considered by workers and government authorities alike as an evil to be averted. This was particularly true in England between 1725 and 1775 when new machines were being widely introduced in the textile industries. The workers involved had no assurance that these labor-saving devices meant anything more to them than lost employment opportunities, and the land owners and sheep raisers saw in the coming rise of the cotton-manufacturing industry the destruction of their own markets for wool. The results were machine-breaking riots, persecution of inventors, and legal restrictions. John Kay, who invented the flying shuttle in 1733, was forced to flee the country; Hargreaves, the inventor of the spinning jenny (1764), was compelled to change his residence; and Crompton, who invented the spinner's mule in 1779, was forced to go into hiding. The prohibition on the manufacture of all-cotton fabrics in England was not lifted until 1774.

Since those early days of our industrial society, every period of widespread unemployment has brought with it a revival of the old protests and the old discussions. The most recent protests against the introduction of labor-saving devices have been no less earnest, albeit less violent, than those of the eighteenth century. Yet we need only to look about us to observe the tremendous multiplication of labor opportunities which past technological improvements have provided in creating vast new industries and new services. The question is whether any economic changes have occurred during recent years and especially during the last two decades which justify the dark prophecies of ever-increasing unemployment that have become current of late.

The vast number of persons unemployed since 1929, and the apparent disparity between recent production increases in certain industries and the extent of reemployment in these industries have aroused new interest in the problem of "technological displacement" and unemployment. With recovery in industry and business manifesting itself in increased production and sales, increased employment, and increased profits and dividends, we face the disturbing realization that estimates of the number of unemployed show no proportionate decrease and that the relief burden remains at a high level. Numerous startling developments in production techniques and some recent dramatic instances of displacement of workers through the introduction of these new techniques have helped to focus attention on the effects of decreasing labor requirements per unit of production on the volume of employment.

A full investigation of the effects of changing technology on the volume of employment and unemployment would involve an analysis of the effects of changing prices of goods and services, of changing costs of capital and labor and the changing proportions of each employed in the production process, of changing demands for goods and services, and of a multitude of other factors which play an important part in determining the profitableness of employing workers. Only such an economic analysis, dealing with the fundamental elements of our economic society, could be expected to arrive at conclusions concerning the underlying causes of unemployment in general and the particular type of unemployment which might be attributed to changing industrial techniques. Such an analysis would have to extend far beyond the size and scope of a report of this nature. Since, however, the net effects of the underlying economic factors find their quantitative expression in the net changes of the volume of production and employment, a brief statistical analysis of the relationship between the total volume of goods and services produced in the country and the number of hired workers engaged in this production offers an approach toward a better understanding of the nature of a problem which has come to be referred to popularly as that of "technological unemployment." While such a statistical analysis may not permit the drawing of any conclusions as to the underlying causes of what occurred during the period under consideration, it at least makes possible an examination of some of the measurable effects in a new light. It is therefore proposed, in this report, to subject the period since 1920 to a bird's-eye view—to examine the available statistical information on the volume of production and employment in the light of the changes in output per man-year which took place during this period, and to bring together data which indicate to what extent employment dislocations have

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occurred and occupational readjustments have been made necessary by the changes in the character and techniques of production.[2]

Production, Employment, and Unemployment

An over-all picture of the changing number of employment opportunities in the light of changing productivity [3] requires over-all measures of the volume of goods and services produced in the country and the volume of hired labor employed in the creation of this national product. The first question then is, How has the volume of goods and services produced varied from year to year since 1920?

The National Output

The statistician faces a great many complex questions, frequently bordering on the metaphysical, when he attempts to construct a measure of the changing volume of total physical production. But inasmuch as such measures, however, crude they may be, are extremely useful as indicators of how well or how badly the economy of the country is faring, a number of attempts have been made to construct them. The results are always hedged around with all manner of qualifications,[4] but the very need for these indexes has resulted in their widespread acceptance. Aside from the usual deficiencies from which such indexes suffer, none of the available indexes of the "physical volume of production" takes into account the volume of commercial services which constitute an important section of our economy. The omission of this growing source of gainful employment has been due primarily to the difficulty of applying appropriate physical measures to this type of economic activity. Since an over-all picture of the changing volume of employment opportunities cannot possibly leave out of consideration this expanding group of industries, it is necessary to use a different, an all-inclusive, measure of the growth of production—the national income.

"Year in, year out the people of this country, assisted by the stock of goods in their possession, render a vast volume of work toward the satisfaction of their wants. Some of this work eventuates in commodities, such as coal, steel, clothing, furniture, automobiles; other takes the form of direct, personal services, such as are rendered by physicians, lawyers, Government officials, domestic servants, and the like. Both types of activity involve an effort on the part of an individual and an expenditure of some part of the country's stock of goods. If all commodities produced and all personal services rendered during the year are added at their market value, and from the resulting total we subtract the value of that part of the nation's stock of goods which was expended (both as raw materials and as capital equipment) in producing this total, then the remainder constitutes the net product of the national economy during the year. It is referred to as national income produced, and may be defined briefly as that part of the economy's end-product which is attributable to the efforts of the individuals who comprise a nation." [5] The "national income produced" thus represents the net value of the goods and services produced through the "efforts whose results appear on the market place of our economy." [6]

In order to convert these monetary values of income produced into measures representing the varying quantities of goods and services produced annually, it is necessary to adjust them for changes in the value of money. This may be done by applying an appropriate index of prices to the monetary value, thus obtaining what may be referred to as the "volume of goods and services produced." It is virtually impossible to construct a completely satisfactory index for deflating monetary national income. Since, however, some index must be used in order to make even a rough adjustment rather than "leave the dollar totals completely uncorrected for the striking changes in the purchasing power of the dollar that occurred" during the period since 1920, it was decided to use the index of "prices of finished goods" constructed by Dr. Simon Kuznets and used by him to adjust "income produced" for changes in purchasing power.[7] The index used is of course subject to all the limitations which are inherent in a fixed-weight composite of its nature. Insufficient importance, for example, is given to consumers' services and "nonessentials" which constituted an increasing proportion of the national income produced over the period. Another criticism might concern the fact that the prices included in the index reflect the prices of goods sold during the year but not necessarily produced that year, while the index of output covers goods produced but not necessarily sold. In general, however, the broad outlines of the deflater used here are much the same as those

[2] A number of surveys designed to collect and analyze both original and published data on these and other aspects of the relationship between employment opportunities and changes in industrial techniques are now in progress under the direction of the National Research Project.

[3] The term "productivity" as used in this chapter means the ratio: quantity output per employee man-year. For further discussion of the concept, see the section on "Over-all productivity."

[4] Arthur F. Burns, *Production Trends in the United States Since 1870* (New York: National Bureau of Economic Research, 1934), pp. 254–261.

[5] U. S. Congress, Senate, *National Income, 1929–32*, S. Doc. No. 124, 73d Cong., 2d sess., 1934, p. 1. For detailed description of the limitations of the concept "national income produced" see ch. I.

[6] Ibid., p. 6.

[7] *Income Originating in Nine Basic Industries, 1919–33* (National Bureau of Economic Research Bulletin 59, May 4, 1936), p. 5. The index was constructed by combining an index of the price of capital goods with the B. L. S. index of the cost of living, using the weights 1 and 9, respectively.

of other indexes prepared for similar purposes and it is felt that despite the weaknesses inherent in any index of this nature the resulting "volume of goods and services" fairly depicts the growth and decline of the national output it purports to represent. More complete data and more refined techniques of measuring both national income and price changes would undoubtedly improve the accuracy of the year-to-year fluctuations, but it is highly questionable whether such improvements would materially change the general picture.

TABLE 1.—*Indexes of monetary income produced, prices of finished goods, and volume of goods and services produced, 1920–35*

[1920=100]

Year	National monetary income produced [1]	Price of finished goods [2]	Volume of goods and services produced [3]
(1)	(2)	(3)	(4)
1920	100	100	100
1921	80	89	90
1922	90	82	110
1923	103	85	122
1924	105	85	125
1925	114	86	132
1926	116	87	133
1927	116	86	135
1928	120	84	142
1929	124	85	146
1930	104	83	125
1931	82	76	108
1932	60	68	88
1933	63	65	97
1934	72	68	106
1935 [4]	79	69	114

[1] For 1920–29, the index is based on "realized income", less "imputed income" plus "business savings" as shown in Levin, Moulton, and Warburton, America's Capacity to Consume (Washington, D. C., 1934), table 5, pp.152–153; this series was spliced to the "income produced" data, 1929–35, as shown in Survey of Current Business, July 1936, p. 18. Income from work relief was excluded.

[2] S. Kuznets, Income Originating in Nine Basic Industries, 1919–34 (National Bureau of Economic Research Bulletin 59, 1936), table 3, p. 24. An index of the cost of capital goods was combined with the B. L. S. cost of living index with weights of 1 and 9, respectively. The figure for 1935 was constructed by the authors, using the same method.

[3] Column (2) divided by column (3).

[4] Preliminary.

NOTE.—All figures were rounded after computations were made.

The three statistical series, monetary income, prices, and the quantitative volume of goods and services produced, are shown in table 1. It will be observed that while the total national monetary income produced rose 24 percent from 1920 to 1929, the total *quantity* of goods and services produced in the country, according to these estimates, increased 46 percent. After the sharp declines during the years 1929 to 1932, the monetary income rose 19 points from 1932 to 1935 to a point equal to 79 percent of the 1920 level, while the physical income climbed 26 points during the same period and reached a level 14 percent higher than the quantity of goods and services produced in 1920. It should be borne in mind, however, that since the population of the country increased 19 percent from 1920 to 1935, the goods and services produced per capita in 1935 were still equal to only 96 percent of the 1920 production.

The National Labor Force

With this over-all picture of the fluctuations in the national output before us we now turn to the second question: How much hired labor was engaged in the creation of this annual product and how much of the labor available for employment remained unused? Again we run into statistical difficulties. While the obstacles encountered with respect to employment and unemployment statistics are different from those encountered in the field of production statistics, it is perhaps equally difficult to determine the number of workers employed during the years from 1920 to 1935. Although the amount of information concerning the volume of employment has grown immensely during the last two decades, the data available for the period prior to 1930 are rather fragmentary and the statistics for the years since 1930, while representing a vast improvement over the preceding period, still leave many fields of economic activity unexplored. It thus again became necessary to gather whatever information was available and to construct the best estimates of employment and unemployment that could be obtained under the circumstances.

United States Census occupation statistics for 1920 and 1930 present data on the number of "persons 10 years old and over gainfully occupied." Since this chapter concerns itself only with the effects of changing productivity on the employment opportunities of those who depend upon paid jobs for their livelihood and are, therefore, subject to unemployment, all enterprisers, self-employed, and unpaid family workers on farms have been subtracted from the census figures in order to arrive at the number of workers "available for employment." The figures for the years between 1920 and 1930 have been interpolated, taking into account the flow of immigration, emigration, and farm-city movements.[8] For the years after 1930 the estimates are based on changes in the age distribution of the population, as well as immigration and farm-city movements, and therefore include those who under "normal" conditions would have obtained their first employment experience but who, during the period of

[8] Gainful workers returning to farms are, like farmers and their unpaid family workers, not considered part of the labor supply so long as they remain on the farm. Their inclusion, however, would make very little difference in the size of the labor supply, since there was a net movement to the farm during the depression of only some 266,000 persons (in 1932), or approximately 100,000 gainful workers. See *Farm Population Estimates* (U. S. Dept. of Agr., mimeographed, Oct. 27, 1936.)

widespread unemployment, may never have worked.[9] It was not found possible to make any adjustments which would take into account variations in the concept of "employability", although it is known that the drastic changes wrought by the depression have, on the one hand, compelled many persons to seek jobs who would otherwise not have been available for employment and, on the other hand, forced many people out of the labor market because of the realization of their inability to obtain employment.

Including therefore, as far as possible, all persons in the United States who are ordinarily employed by others, we arrive at an estimate of the total of the country's supply of labor for hire each year. It is known, however, that a portion of the labor supply at any given time is actually not available for work because of illness, vacations, voluntary transfers between jobs, labor disputes, and similar reasons for idleness. On the basis of the 1930 census data on unemployment, it is estimated that approximately 2½ percent of the total supply of workers is "unusable" for these reasons.[10] The remainder of the labor supply represents the country's total manpower available for hire. (See table 2 and fig. 1.)

The next step involved the construction of estimates of the proportion of this available manpower which was actually employed in the creation of the goods and services produced each year. Data available in the United States Bureau of the Census, the United States Bureau of Mines, the United States Bureau of Labor Statistics, and the Interstate Commerce Commission were used for this purpose, together with the data published by the Ohio State Department of Industrial Relations which give rather complete information on employment fluctuations in the various fields of economic activity. The annual estimates based on these sources represent averages of the total number of workers who appeared on pay rolls during each year since 1920. Since the sources make no distinction between part-time and full-time employees, the unadjusted averages considerably overstate the amount of labor-time used in production. It was essential, therefore, to reduce the number employed to "full-time equivalents" in order to arrive at the number of man-years of work that were actually employed.

FIGURE 1
ESTIMATES OF SUPPLY OF LABOR FOR HIRE, EMPLOYED AND UNEMPLOYED, 1920–1935
(TOTAL SUPPLY FOR 1920=100)

INDEX NUMBERS
AVAILABLE SUPPLY OF LABOR FOR HIRE (MAN-YEARS)
TOTAL SUPPLY OF LABOR FOR HIRE
UNUSABLE MAN-YEARS
UNEMPLOYMENT (MAN-YEARS)
EMPLOYMENT (MAN-YEARS)
1920 1921 1922 1923 1924 1925 1926 1927 1928 1929 1930 1931 1932 1933 1934 1935

TABLE 2.—*Estimates of the supply of labor for hire, employed and unemployed, 1920–35*

Year	Total supply of labor for hire[1] (1920=100)	Unusable man-years, as percent of total supply in 1920[2]	Available man-years				
			Total as percent of total supply in 1920[3]	Employed		Unemployed	
				Index[4] (1920=100)	As percent of total supply in 1920[5]	As percent of total supply in 1920[6]	As percent of available supply each year[7]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1920	100.0	2.5	98	100	92	6	6
1921	102.2	2.6	100	81	74	25	25
1922	104.8	2.6	102	87	80	22	22
1923	107.4	2.7	105	102	93	11	11
1924	110.0	2.8	107	101	93	14	13
1925	112.4	2.8	110	104	96	14	13
1926	114.8	2.9	112	108	99	13	11
1927	117.1	2.9	114	110	101	14	12
1928	119.2	3.0	116	111	102	15	13
1929	121.1	3.0	118	116	107	12	10
1930	122.8	3.1	120	106	98	22	19
1931	124.2	3.1	121	90	82	39	32
1932	125.1	3.1	122	73	67	55	45
1933	126.7	3.2	124	72	66	58	47
1934	128.5	3.2	125	79	73	53	42
1935	130.2	3.3	127	82	75	52	41

[1] Excludes enterprisers, self-employed, and unpaid labor on farms.
[2] Allowance of 2.5 percent of the total labor supply for sickness and similar lost time.
[3] Column (2) less column (3)
[4] Estimated full-time man-year equivalents of the average annual number of wage and salaried workers employed. The adjustments for part-time unemployment were based on data from 11 studies made in various cities.
[5] Obtained by multiplying column (5) by the percentage found for 1920 (91.9).
[6] Column (4) less column (6).
[7] Column (7) divided by column (4).

NOTE.—All figures except columns (2) and (3) have been rounded off after computation.

[9] The Census of Occupations includes only those who either have or at one time had a "usual occupation."

[10] The 1930 Census of Unemployment reported that of the total "gainful persons" in 1930 approximately 1,000,000 workers, or 2 percent, were not available for work for these reasons. The groups included in this calculation consist of the following census classes: class C—persons out of a job and unable to work; class D—persons having jobs but idle on account of sickness or disability; class E—persons out of a job and not looking for work; class F—persons having jobs but voluntarily idle without pay. To these classes were also added that portion of those listed under class A (persons out of a job, able to work, and looking for work) and class B (persons having jobs but on lay-off without pay, excluding those sick and voluntarily idle) who were not working because of: voluntary absence, personal disability, family reasons, labor disputes, and dissatisfaction with the job.

Inasmuch as these million workers probably belonged almost entirely to the employee group considered in this chapter as constituting labor supply (instead of the entire census class "gainful persons"), it is estimated that at any time approximately 2½ percent of the total labor supply is not available for work.

While the concept "man-hour" of work is definitely circumscribed in the sense that every hour consists of 60 minutes, the concepts "man-week" and "man-year" are ever changing because over a period of years the standard work week may vary in the number of man-days it contains and the man-days in turn may vary in their man-hours content. It is known, for instance, that during the last few decades the man-hours content of a standard man-year has declined considerably. When the standard work week consisted of 6 days of 10 hours each, the man-year, allowing for 12 holidays, consisted of 3,000 man-hours; during more recent years the standard work-week in many industries has been limited to 5½ days of 8 hours each or, allowing for holidays, to a little over 2,000 man-hours. For the purpose of measuring changing volume of output in relation to the time actually worked, it would therefore be necessary to measure employment in terms of man-hours of work, but from the standpoint of the number of jobs, the 3,000-hour man-year represents one full-time job for 1 year in the same sense in which the 2,000-hour man-year represents one full-time job for another year. Thus, a worker employed 44 hours a week when the standard week consisted of 60 hours would be regarded as a part-time employee, while the same employee working the same hours during a period when 44 hours constituted a standard work-week would be regarded as fully employed. For the purpose at hand it was therefore considered appropriate to use each year's prevailing-hours content as representing a man-year of work and to make the part-time adjustments with this flexible man-year concept in mind.

If the term "fragmentary" is accepted as descriptive of the available employment statistics, some adjective connoting infinitesimally small particles would have to be used to describe the availability of data on part-time employment. However, utilizing the results of 11 studies from which it was possible to obtain the amount of time lost by part-time workers, adjustments were made in the estimates of the average number of workers employed each year.[11] The resulting index of employment measured in full-time man-years is shown in column (5) of table 2.

Regarding the annual estimates of the available labor supply as representing man-years available for employment and deducting from them the man-years of labor actually employed, the balance may be referred to as "unemployed man-years."[12] (See columns (7) and (8), table 2.)

The disparity between the amount of labor available and the amount used for production is evident from the figures in table 2. Although employment (in man-years) increased 16 percent from 1920 to 1929, the total labor supply increased 21 percent during the same period. Unemployment—excluding the unusable man power—during the highly prosperous twenties fell to as low as 10 percent of the available manpower during only a single year. The expansion in output and employment during this period did not suffice to bring unemployment down to its 1920 level, although it did effect a substantial reduction from the 1921 figure of 25 percent unemployed.

The sharp drop in production subsequent to 1929 and the continued growth of the labor supply resulted in an increase in the unemployed man-power to almost a third of the total available in 1931, and to 47 percent in 1933. With increasing production, the volume of unemployment has since declined gradually to two-fifths of the total available man-power in 1935—still, however, nearly nine times the volume of unemployment in 1920.[13]

Two important points emerge from the data presented in tables 1 and 2. On the one hand, by 1935 the disparity between the movement of production and employment had reached a point where the former stood at 114 percent of 1920 while the latter was at only 82 percent of the same year. On the other hand, it is clear that if the ratio of output to employment had not increased substantially the level of production of 1929 could not have been attained, since the available labor supply increased only 21 percent between 1920 and 1929 while output expanded 46 percent. In the following section some of the characteristics of the changing ratio of output per man-year will be discussed in relation to changes in total production and employment.

Productivity and Employment Opportunities

It was pointed out previously that, while the volume of total employment in 1935 was still 18 percent below the 1920 level, the volume of goods and services produced in 1935 was 14 percent higher than in 1920. Another way of stating the same thing would be to say that, while production in 1935 was 14 percent above 1920, the "productivity" of hired workers was 39 percent higher or the "unit labor requirement" was

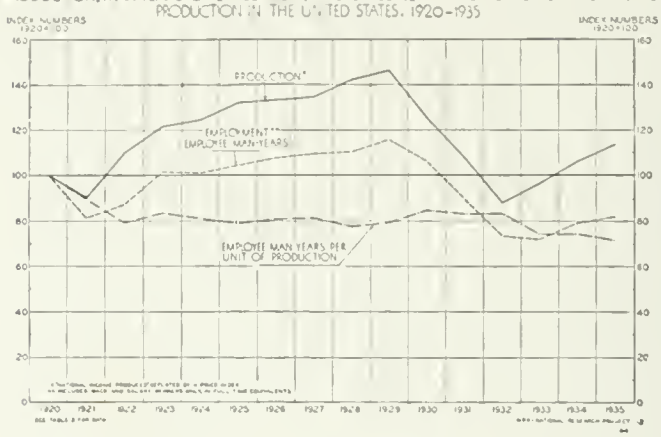
[11] The 11 studies were made in Columbus, Buffalo, Syracuse, and Louisville at different times during the 16-year period under consideration.

[12] Since available labor supply and employment are given in terms of full-time equivalents, the unemployed manpower also represents full-time man-years, that is, 10 men employed half time are represented in these estimates as 5 man-years employed full time and 5 unemployed.

[13] It should be kept in mind that the percentages of unemployed manpower, as given in this chapter, include part-time unemployment and are computed on a base which includes only wage and salaried workers. These percentages are therefore considerably higher than similar ratios which do not count part-time unemployment and are computed on the numerically larger base of total "gainful persons" which include enterprisers, self-employed persons, and unpaid family labor on farms.

28 percent lower.[14] If we bring together the over-all production data given in table 1 and the over-all employment data given in table 2 we can obtain ratios similarly for each of the years from 1920 to 1935. These ratios are presented in table 3 and in figure 2.

FIGURE 2
PRODUCTION, MAN-YEARS OF EMPLOYMENT, AND EMPLOYEE MAN-YEARS PER UNIT OF TOTAL PRODUCTION IN THE UNITED STATES, 1920–1935



Over-all Productivity

An examination of table 3 will show that while 146 units of the Nation's output were being produced in 1929 for every 100 units in 1920, only 16 percent more man-years of work were employed in 1929. This disparity between the increases in production and employment is of course reflected in the productivity figures, which indicate that the major spurt took place during the depression of 1921 and the recovery of 1922. It should also be noted that, while another substantial increase in productivity took place after 1930, during the period from 1922 to 1929 the productivity figures show only a slight upward tendency in spite of the fact that such other information as is available points to substantial and continuous increases in productivity in practically every field of economic activity. These fluctuations raise a number of questions with reference both to the underlying statistical material and to the varied movements which are concealed by the over-all figures and the averages derived from them.

First of all, it should be made very clear that the figures presented here do not measure the changing efficiency of labor in the sense that this is done in time-and-motion studies of operations and processes in the manufacture of a given product. Nor do the ratios measure the relationship between the total national output and the labor time of *everyone* engaged in producing it, since the employment index is restricted to wage and salaried workers. Between these two extremes lie any number of meaningful ratios which might be constructed to show the changing relationship between the output of a plant, an industry, or a group of industries and all or any part of the labor force engaged in its production. The ratios presented here have been constructed to show the changing relationship between the volume of employment and the Nation's output, so that the unit-labor-requirement ratio indicates changes in man-years employed per unit of total output. The movement of this ratio is affected not only by changes in the character of the total output and in the industrial methods used in production, as described in succeeding pages, but also by the fact that a growing proportion of the Nation's work is performed by hired workers. The movement of this ratio therefore indicates the changes — whatever the causes — in *employment opportunities* per unit of output.

When we add the total of nonemployees (employers, self-employed, and unpaid family workers on farms) to the man-years employed each year, the resulting employment index rises more slowly from 1920 to 1929 than the index which excludes nonemployees, due

TABLE 3.—*Indexes of production, employment, productivity, and unit labor requirement, 1920–35*

[1920=100]

Year	Production[1]	Man-years of employment[2]	Productivity: Production per employee man-year[3]	Unit labor requirement: Employee man-years per unit of production[4]
(1)	(2)	(3)	(4)	(5)
1920	100	100	100	100
1921	90	81	111	90
1922	110	87	126	79
1923	122	102	120	84
1924	125	101	123	81
1925	132	104	127	79
1926	133	108	124	81
1927	135	110	123	81
1928	142	111	129	78
1929	146	116	126	79
1930	125	106	118	85
1931	108	90	120	83
1932	88	73	120	83
1933	97	72	134	74
1934	106	79	134	74
1935[5]	114	82	139	72

[1] Same as column (4), table 1.

[2] Same as column (5), table 2.

[3] Column (2) divided by column (3). Although the production series includes the output of the entire economy, the employment index excludes enterprisers, unpaid family workers on farms, and the self-employed. The productivity index therefore represents the ratio of total output to the man-years of only wage and salaried workers, i. e., of those subject to unemployment. See footnote 14.

[4] Column (3) divided by column (2). See note 3 above.

[5] Preliminary.

NOTE.—All figures were rounded after computations were made.

[14] The term "productivity" as used throughout this chapter, unless otherwise indicated, means the ratio: *total* output per *employee* man-year, and inversely, "unit labor requirement" means the ratio: employee man-years per unit of *total* output. The difference between these ratios and some other meaningful ratios of "productivity" is explained later.

to the long-term decline in the proportion of these nonemployee groups in the total. Nor does the index which includes nonemployees decline nearly so much during the depression periods because the nonemployees are not subject to "unemployment" in anywhere near the same degree as hired workers. As is to be expected, the index of output per man-year when the nonemployees are included is lower in depressions and higher in periods of activity than the index based on employees alone. (The differences are shown in figs. 3a and 3b.) Since this chapter is concerned primarily with the employment opportunities of workers, the pages which follow will discuss only the ratios based on employee man-years.

While the underlying statistical material has already been sufficiently qualified, attention is again directed to the fact that the roughness of the raw material is, perhaps as much as any other factor, responsible for some of the year-to-year changes in the productivity figures. This may in part explain the declines in productivity shown in some years, although

FIGURE 3A
TOTAL PRODUCTION AND EMPLOYMENT IN THE UNITED STATES, 1920–1935

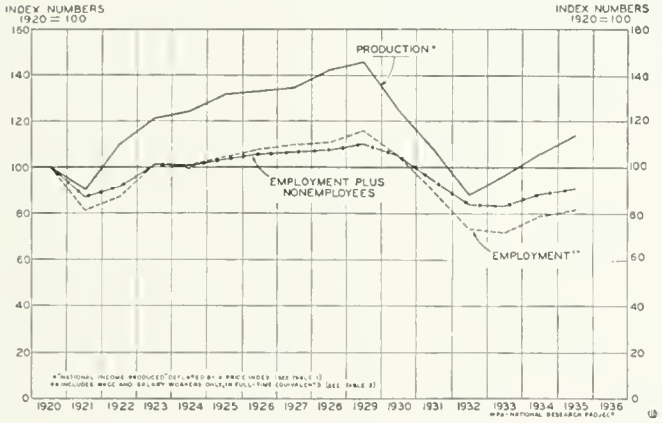
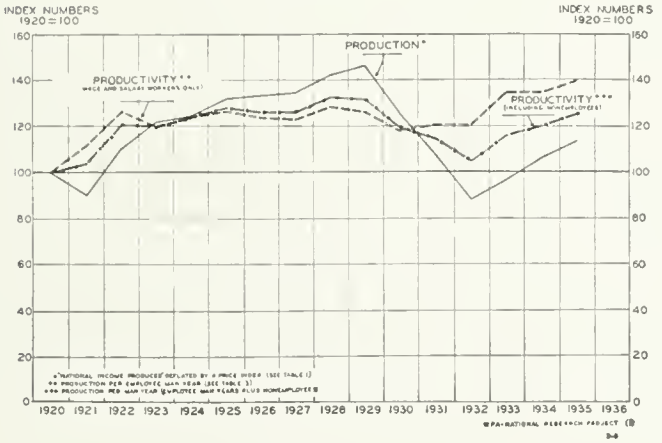


FIGURE 3B
TOTAL PRODUCTION AND PRODUCTIVITY IN THE UNITED STATES, 1920–1935



it is by no means improbable that these figures reflect the effect of such other factors as declines in the annual level of utilized capacity or the employment of less efficient labor during peaks of production. The reduced man-hour content of the full-time man-year should also be taken into consideration, especially in the interpretation of the productivity data for the period after 1929, inasmuch as it serves to conceal the extent of the increase in man-hour productivity which occurred during the latter years.

More important, however, is the fact that both the year-to-year fluctuations and the productivity plateau during the period from 1922 to 1929 also reflect the changing relative importance of the several fields of industrial activity and the different absolute levels of productivity characteristic of them. This point will perhaps be made clearer by a more detailed discussion of the character of the type of composite ratio shown in table 3. Let us assume that two plants produced the same product. Plant A, highly mechanized, maintained a level of productivity approximately twice as high as that of plant B. Let us now assume that each plant increased both its production and productivity, but that the relative increases in the two plants were those given in the table below:

Plant	Year		Percentage change
	First	Second	
Plant A:			
Production	2,000	2,100	+5.0
Employment	1,000	1,000	0
Productivity	2.00	2.10	+5.0
Plant B:			
Production	2,000	3,100	+55.0
Employment	2,000	3,000	+50.0
Productivity	1.00	1.03	+3.0
Total, both plants:			
Production	4,000	5,200	+30.0
Employment	3,000	4,000	+33.3
Productivity	1.33	1.30	−2.3

It will be noted that in spite of productivity increases in both plants, the over-all productivity declined. In one sense this decline in productivity is real inasmuch as in the second year a larger proportion of the total product was produced at a lower level of productivity than in the first year. In another sense, however, the decline in the average is misleading inasmuch as it fails to indicate that productivity increased in both plants—perhaps as a result of improvements in production techniques.

This highly simplified hypothetical example—which might have been constructed to show the opposite re-

sult—illustrates the type of change which actually takes place continuously in a competitive economy. Here not only the relative importance of different plants in the same industry changes, but the relative importance of entire industries shifts materially over relatively short periods of time. These shifts are frequently due, in large measure, to changes in industrial techniques, the discovery of new ways of doing old things, the invention of new machines, the development of new products, the growth of new industries, and the rise of services which were formerly performed either in the home or not at all. Because of these manifold reasons, any study of the effects of changing productivity on the volume of employment must attempt to get behind over-all figures and study the changes in the component industries.

Trends in Basic and Service Industries

The increase of 16 percent in total employment from 1920 to 1929 was the result of an increase of only 3 percent in the "basic" industries—agriculture, mining, manufacture, construction, transportation, communication, and public utilities—and of nearly 50 percent in the "service" industries—trade, professional service, public service, and personal and domestic service. While employment in the service industries after 1929 never fell to the 1920 level, even during the low point of the depression, and stood 13 percent higher in 1935 than in 1920, the level of man-year employment in the basic industries was, even in 1935, still 32 percent below 1920. (See table 4.)

The effect of this divergence in the trend of employment in the basic and in the service industries on the proportion each group comprised of the total employment is indicated in table 5 and figure 4a. The proportion of total man-years of employment represented by service activities increased continuously except in the years of recovery immediately after a depression low: 1922–23 and 1933–35. From 30 percent of the total in 1920, service employment rose to 38 percent in 1929; by 1932, because of the more rapid decline in basic employment, the proportion employed in the service industries had reached the high point of 44 percent, after which, with the growth of reemployment in the basic industries, it receded to 42 percent in 1935. It remains to be seen whether the past long-term expansion of the service activities will again be resumed or whether the proportions which obtained during the late 1920's represent the saturation point in the proportion of service employment.

FIGURE 4A

COMPOSITION OF TOTAL MAN-YEARS OF EMPLOYMENT, 1920-1935

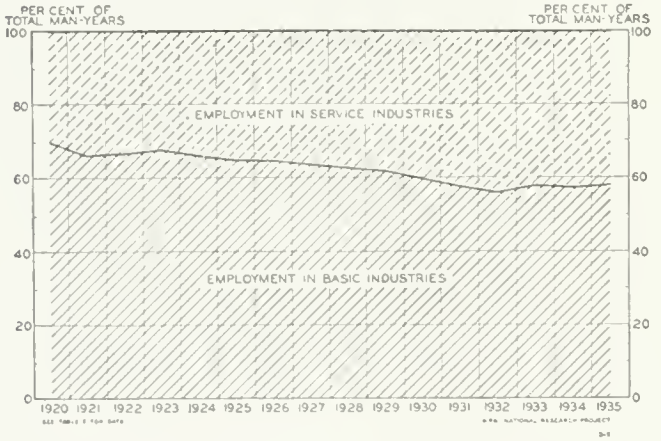


FIGURE 4B

COMPOSITION OF EMPLOYEE MAN-YEARS PER 100 UNITS OF TOTAL PRODUCTION, 1920-1935

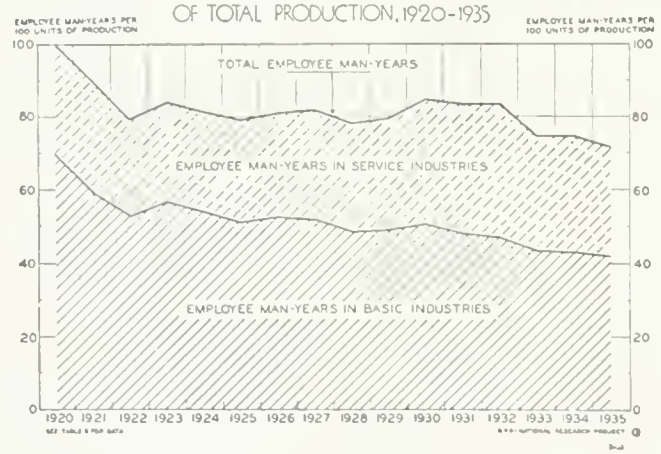

EMPLOYEE MAN-YEARS PER 100 UNITS OF PRODUCTION
EMPLOYEE MAN-YEARS PER 100 UNITS OF PRODUCTION
TOTAL EMPLOYEE MAN-YEARS
EMPLOYEE MAN-YEARS IN SERVICE INDUSTRIES
EMPLOYEE MAN-YEARS IN BASIC INDUSTRIES
100
80
60
40
20
0
1920 1921 1922 1923 1924 1925 1926 1927 1928 1929 1930 1931 1932 1933 1934 1935

TABLE 4.—*Indexes of man-years of employment in basic and in service industries, 1920–35*

[1920=100]

Year	Total man-years of employment [1]	Man-years of employment in basic industries [2]	Man-years of employment in service industries [2]
(1)	(2)	(3)	(4)
1920	100	100	100
1921	81	77	91
1922	87	83	96
1923	102	99	109
1924	101	96	114
1925	104	97	122
1926	108	100	126
1927	110	100	133
1928	111	99	138
1929	116	103	146
1930	106	91	141
1931	90	74	125
1932	73	59	106
1933	72	60	100
1934	79	65	111
1935	82	68	113

[1] Same as column (5), table 2. See footnotes to table 2.

[2] The basic industries include agriculture, forestry and fishing, mining, manufacturing, construction, transportation, communication, and electric light and power. All other activities, such as recreation, trade, professional service, personal service, and public service are included under "service." All employees of the respective industries are included in each category. Thus, a bookkeeper or an engineer employed by a manufacturing concern would be included in the "basic" industries, while a stenographer or porter employed in a physician's office would be in the "service" industries. In agriculture only hired labor is included.

The extent of the decline in the relative importance of basic industry employment in the production of the total income of the country is shown in table 6 and figure 4b, which present the changing composition of the hired-labor requirements per unit of the total output. From table 6 it appears that of each 100 man-years of labor engaged in the production of 100 units of the total output in 1920, 70 man-years were expended in basic industries and 30 in service, whereas of the 79 man-years of work per 100 units of the total output in 1929, only 49 were employed in basic and 30 in service activities. By 1935 the total hired labor requirements per 100 units of the total output dropped to 72 man-years, of which 42 were expended on basic and 30 on service activities.

TABLE 5.—*Composition of total man-years of employment, 1920–35*

Year	Total employment	Percent of total employed in—	
		Basic industries	Service industries
(1)	(2)	(3)	(4)
1920	100	70	30
1921	100	66	34
1922	100	67	33
1923	100	68	32
1924	100	66	34
1925	100	65	35
1926	100	65	35
1927	100	64	36
1928	100	63	37
1929	100	62	38
1930	100	60	40
1931	100	58	42
1932	100	56	44
1933	100	58	42
1934	100	58	42
1935	100	58	42

NOTE.—See table 4 for the indexes of each group.

These figures should not be interpreted to mean that the increase in over-all productivity was the net result of rising productivity in basic industries and stable or declining productivity in service industries, and that the productivity "plateau" from 1922 to 1929 is therefore the result of increases in productivity in basic industries, offset by productivity declines in service. The fact is that, even if similar relative increases in productivity had occurred in both fields, a leveling off of the index of labor required per unit of output would have taken place if, during the same period, service activities had accounted for a rapidly growing proportion of the total output. In the light of the available data it is not at all improbable that this situation actually obtained during the years from 1922 to 1929.

TABLE 6.—*Employee man-years per unit of total output, 1920–35*

[1920=100]

Year	Total employee man-years per unit of output [1]	Composition of total [2]	
		Employee man-years in basic industries	Employee man-years in service industries
(1)	(2)	(3)	(4)
1920	100	70	30
1921	90	59	31
1922	79	53	26
1923	84	57	27
1924	81	54	27
1925	79	51	28
1926	81	52	29
1927	81	52	30
1928	78	49	29
1929	79	49	30
1930	85	51	34
1931	83	48	35
1932	83	47	36
1933	74	43	31
1934	74	43	32
1935 [3]	72	42	30

[1] Same as table 3, column (5).

[2] Obtained by applying to column (2) the changing percentage distribution for each year shown in table 5.

[3] Preliminary.

NOTE.—All figures were rounded after computations were made.

The sharp reduction in the volume of labor per unit of output which occurred between 1920 and 1922 may be attributed in large part to the fact that rapidly increasing productivity in the basic industries as a whole was not yet being offset by the expansion of service activities. As indicated in table 4, the tremendous growth of service employment did not begin until 1923, resulting in the productivity "plateau" of the twenties.

In connection with the 1930 increase in labor employed per unit of output, it should be noted that man-years of employment in the service industries held up very well in that year, but when service employment started to fall it continued to do so for a year longer than did basic employment, which by 1933 had begun to turn upward. In this year, when service employment was still falling, total labor employed per unit of output registered a decline of over 10 percent. A large part of the increase in productivity after 1932 may be attributable to the improvements which Professor Clark has indicated "stand ready for introduction when confidence revives sufficiently and when the condition of the capital market makes it possible to raise the necessary funds."

Employment Trends In Basic Industries

In the same way in which light was thrown on the movements of over-all productivity by a breakdown of the total into two major groups, further clarifica-

tion may be obtained by a more detailed examination of one of these groups—the basic industries. Employment in the basic industries as a whole did not expand very much from 1920 to 1929; in fact, employment exceeded the 1920 level only during the years 1926 to 1929. This stability of employment with respect to the group as a whole did not, however, characterize the movements of the component industries. Some were shrinking in employment while maintaining production, some experienced declines in both employment and production, while others were increasing both employment and production at a rapid pace.

Only two groups of the basic industries shown in table 7 were expanding in employment from 1920 to 1929—construction and communication and transportation (other than steam railroads). Agriculture and forestry and fishing maintained their proportion, together comprising 13 percent of total employment both in 1920 and in 1929. Mineral extraction declined from 6 to 5 percent of the total, steam railroads from 10 to 8 percent, and manufacturing from 51 to 49 percent.

The general depression after 1929 affected the several groups variously. Construction suffered the most marked decline, falling from 11 to 6 percent of the shrinking total. Steam railroads continued to lose in relative importance, dropping from 8 to 7 percent. The other groups increased their proportion of the total by resisting the general decline more effectively than these two industries.

Just as employment in the service industries has become an increasing proportion of the total, so, within each of the basic industries, the "service" occupations have increased their proportion of total employment. This tendency is illustrated by the following data for the State of Ohio:[15]

Industry and occupation groups	Percent of total employees in each group			
	1916	1920	1925	1929
Manufacturing	100.0	100.0	100.0	100.0
Wage earners	92.1	90.1	89.6	89.0
Office workers	7.2	9.2	9.4	9.8
Salespeople	.7	.7	1.0	1.2
Transportation and public utilities	100.0	100.0	100.0	100.0
Wage earners	89.9	87.3	85.5	81.4
Office workers	9.8	12.3	13.8	17.4
Salespeople	.3	.4	.7	1.2
Construction	100.0	100.0	100.0	100.0
Wage earners	(1)	93.9	93.4	92.4
Office workers	(1)	5.2	5.3	6.2
Salespeople	(1)	.9	1.3	1.4

[1] Not available.

Data for individual manufacturing industries in Ohio and in the United States as a whole reveal a similar and in many cases a more marked trend.

Productivity Changes In Selected Basic Industries

Very real and substantial increases in productivity took place in most of the industries whose output and employment go to make up the totals referred to in the preceding pages. With few exceptions, individual industries were able in one way or another to reduce the labor required per unit of output. While employment increased in most of these industries during the 1920's, although less rapidly than output, some industries were actually able to reduce the number of employees in the face of expanding production.[16]

[15] Computed from data in Average Annual Wage and Salary Payments in Ohio, 1916 to 1932 (U. S. Bureau of Labor Statistics Bull. No. 613), pp. 24, 39, 176.

[16] The National Research Project of the Works Progress Administration is conducting a number of surveys of changes in production, employment, and productivity in various industries. These surveys are being made in cooperation with other agencies, both public and private: Bureau of Labor Statistics, Bureau of Mines, Railroad Retirement Board, Department of Agriculture, National Bureau of Economic Research, and others.

TABLE 7.—*Distribution of employment in the basic industries, 1920–35*[1]

Basic industries	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935
Index of employment [2] (1920=100)	100.0	82.0	88.8	100.0	97.9	99.1	101.5	101.8	101.2	101.4	94.4	81.2	69.1	69.9	74.7	77.4
Composition of total [2]	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Agriculture [3]	12.0	14.6	13.6	12.1	12.5	12.4	12.2	12.2	12.3	12.0	13.3	14.9	15.9	15.6	13.1	13.2
Forestry and fishing	1.1	1.3	1.2	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0	.9	1.0	1.0
Extraction of minerals	6.0	7.1	6.9	6.6	6.3	6.0	5.9	5.9	5.5	5.3	4.9	4.8	4.5	4.4	4.7	4.5
Manufacturing [4]	51.0	46.6	47.7	48.8	47.7	47.6	47.1	47.0	47.5	48.9	47.1	46.6	49.1	50.3	53.2	53.7
Construction	8.5	9.0	9.7	10.1	10.8	11.3	11.3	11.7	11.8	11.0	11.1	9.6	7.1	6.7	6.1	6.0
Steam railroads	10.2	9.7	9.8	9.9	9.5	9.4	9.4	9.1	8.7	8.4	8.6	8.4	8.1	7.5	7.4	7.0
Other transportation and communication [5]	6.3	7.1	6.7	6.9	7.6	7.7	8.7	8.7	9.0	9.0	9.4	9.5	9.4	9.3	9.4	9.2
Industry not specified [6]	4.9	4.6	4.4	4.5	4.5	4.5	4.4	4.4	4.2	4.4	4.6	5.2	5.0	5.2	5.1	5.4

[1] See text relating to table 2 for sources of estimates.

[2] Not adjusted for part-time employment. Both wage and salaried workers are included.

[3] Hired farm workers only.

[4] Includes electric light and power; excludes steam railroad repair shops and automobile repair shops.

[5] Includes garages, automobile repair shops, air transportation, express companies, livery stables, pipe lines, radio broadcasting, street railways, telephone and telegraph communication, truck, transfer, and cab companies, and water transportation.

[6] Includes nearly a million workers estimated as employed in various basic industries.

The nature of the fluctuations in production, employment, and unit labor requirements in several industrial fields for which data are at hand is shown in table 8.

Man-hour requirements per unit of output in manufacturing industries as a whole were cut nearly in half between 1920 and 1934. Except for minor set-backs in 1923, 1929, 1933, and 1934, man-hours required per 100 units of output declined steadily from 100 in 1920 to 56 in 1934. The rise of 40 percent in output up to 1929 took place with no additional man-hours; in fact, there was a drop of nearly 2 percent.

In view of the progressive reduction in the labor requirements per unit of output in the extractive industries, the number of man-days worked dropped nearly 20 percent between 1920 and 1929, although output increased about 6 percent. The decline in output per man-day which occurred during 1933 and 1934 is attributable primarily to the decrease in the length of the working day and not to declines in technical efficiency. In general it should be kept in mind that many technological improvements in the extractive industries do not result in increased productivity but serve merely to offset the increased difficulties of operation growing out of the depletion of deposits.

The increased efficiency of railroad operation, combined with a relatively stable volume of traffic from 1920 to 1929, resulted in a drop in total man-hours worked of more than 20 percent during the period. From 1929 to 1934 man-hours declined almost 50 percent more while traffic fell off 40 percent, so that by 1934 the man-hours requirement per unit of output was only 74 percent of the 1920 level.[17]

Using a composite index of the number of local and toll telephone conversations, it is found that the output in the telephone industry rose from 100 in 1920 to 185 in 1929, while employment increased only 58 percent. The decline in the volume of business after 1929 was accompanied by an even sharper drop in employment, so that output per employee increased almost as much from 1929 to 1934 as it had in the preceding 10 years. One of the significant technological factors in reducing the labor requirements per unit was the increasing utilization of the automatic dial system. After 1929, however, a number of factors contributed to raising the ratio of output to employ-

[17] A great deal in the way of data essential for analysis of the changing output per man-hour in railroads has been compiled by the Bureau of Labor Statistics; see Witt Bowden, "Productivity, Hours, and Compensation of Railroad Labor," *Monthly Labor Review* (U. S. Dept. of Labor), December 1933, January and February 1934.

TABLE 8.—*Indexes of output, employment, and unit labor requirement in 4 industries, 1920–34*

[1920=100]

Industry	1920	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934
Manufacturing:															
Output [1]	100.0	78.3	98.1	111.3	105.6	116.9	122.6	122.6	132.1	140.6	118.8	101.9	78.3	87.8	94.4
Man-hours [2]	100.0	71.7	85.1	98.2	86.7	91.9	93.7	90.7	91.2	98.1	77.2	60.1	43.0	48.3	52.5
Unit labor requirement [3]	100.0	91.6	86.7	88.2	82.1	78.6	76.4	74.0	69.0	69.8	65.0	59.0	54.9	55.0	55.6
Mining:															
Output [4]	100.0	75.7	76.3	105.5	95.8	96.8	108.1	101.7	99.7	105.5	91.7	72.5	54.0	57.5	65.4
Man-days [5]	100.0	72.8	70.2	94.1	87.2	85.8	94.6	86.4	81.1	82.8	70.4	53.9	40.4	44.8	52.8
Unit labor requirement [6]	100.0	96.2	92.0	89.2	91.0	88.6	87.5	85.0	81.3	78.5	76.8	74.3	74.8	77.9	80.7
Steam railroads:															
Output [7]	100.0	75.9	81.1	96.1	90.7	95.3	100.8	97.0	96.7	99.2	85.0	68.7	52.1	54.7	59.2
Man-hours [8]	100.0	76.1	79.2	90.5	83.3	83.2	85.8	83.0	79.2	79.8	69.0	55.8	43.7	41.0	44.0
Unit labor requirement [3]	100.0	100.3	97.7	94.2	91.8	87.3	85.1	85.6	81.9	80.4	81.2	81.2	83.9	75.0	74.3
Telephone communication:															
Output [9]	100.0	107.2	118.6	128.0	135.0	143.7	153.3	161.2	171.3	185.0	181.8	174.5	156.3	145.4	150.0
Employment [10]	100.0	103.3	105.9	116.7	125.0	130.1	134.6	138.2	145.8	158.3	160.0	140.3	127.2	116.7	112.8
Unit labor requirement [11]	100.0	96.4	89.3	91.2	92.6	90.5	87.8	85.7	85.1	85.6	85.8	80.4	81.4	80.3	75.2

[1] Physical volume of production, based on Census of Manufactures data. From Simon Kuznets, Income Originating in Nine Basic Industries, 1919–34; National Bureau of Economic Research Bulletin 59, p. 24. Base shifted to 1920.

[2] Covers factory workers only. Constructed from Bureau of Labor Statistics index of factory employment and National Industrial Conference Board average hours worked in manufacturing industries.

[3] Man-hours per unit of output.

[4] Excludes petroleum, natural gas, sand, and gravel, since man-day data are not available for these industries. Constructed by the aggregative method, based on the 1923–25 average unit value. From Bureau of Mines published and unpublished data.

[5] Based on man-days worked in mines covering approximately 90 percent of the employment in their industries. Includes all major products except those mentioned in (4). Constructed by aggregating the man-days reported for each industry and dividing through by the 1920 total. From Bureau of Mines published and unpublished data.

[6] Man-days per unit of output.

[7] Weighted average of freight-ton miles and passenger miles. From Kuznets, op. cit., p. 24. Base shifted to 1920.

[8] Covers all class I railway employees, excluding terminal and switching companies. From annual reports of the Interstate Commerce Commission.

[9] Weighted average of exchange and toll connections. From Kuznets, op. cit., p. 24. Base shifted to 1920.

[10] Based on the year-end employment of the Bell Telephone System, excluding Western Electric and Bell Laboratories, as reported in Moody's Manual of Investments: Public Utility Securities (1920–35). Annual employment was estimated by averaging the preceding and current year-end employment. Bell accounts for approximately 95 percent of the total telephone business. Index is biased upward slightly because of the growth of Bell System as compared with all telephone companies.

[11] Employees per unit of output. No data are available for making adjustments for changes in working hours, which were reduced after 1929. Such an adjustment would lower the unit labor requirements. Elimination of bias indicated in (11) would have similar effect.

ment without actually entailing any technological change. Among them are the decline in the amount of construction work, which reduced the number of employees without a corresponding effect on the measure of output, and the reduction in the number of employees "in training" for future expansion.[18]

Summary

The divergency of the trends of employment in the several industrial groups discussed and the variations in the extent of their productivity changes make it clear that the over-all productivity ratios derived from the data on total national income and total employment cannot be interpreted as measures of the extent of technological advance in individual industries any more than the per capita monetary national income figures can be used as measures of the incomes of individual groups in society. If the total national income is regarded as a changing composite of goods and services, however, these over-all productivity figures can be looked upon as measures of the changes in the relationship between total output and the size of the Nation's labor force employed in the creation of this composite or, inversely, as a measure of changing employment opportunities per unit of total output. From this point of view there is definite meaning to the statement that the Nation's output increased 46 percent from 1920 to 1929 with a simultaneous increase of only 16 percent in the Nation's labor force. For it is this circumstance that represents part of the answer to the oft-repeated question: Why was there still a tremendous volume of unemployment in 1935 although most business indicators show that business was about as good during 1935 as it was during the prosperous years of 1923–25?

Many people have become accustomed to thinking of the middle twenties as "normal" and so have come to imply a return to that normal as the desired goal. This attitude overlooks the fact that a country like the United States, with its continuously increasing population, must regard "normal" as a process of ever-increasing levels of production, employment, and income. If labor productivity remained constant, the level of production would have to rise as fast as the labor supply in order to keep the volume of unemployment from increasing. Given our progressive technology and the fact that, with increasing productivity, a decline in production results in a more than proportional decline in employment and an increase in production results in a less than proportional increase in employment, we must contrive to increase the volume of production at a rate which is faster than the rate of increase of our labor supply or else we face the problem of an ever-increasing volume of unemployment.

While the volume of production has from 1932 to 1935 actually been increasing faster than the labor supply, the increase has, in the light of the simultaneously rising productivity, not been rapid enough to absorb more than a fraction of the total unemployed manpower. Although the physical volume of production in 1935 was approximately 30 percent higher than in 1932 and 14 percent higher than in 1920, a rough calculation indicates that a return to the 1929 level of *employment* would, assuming the 1935 composition of the national output and the 1935 rate of productivity, require an output of goods and services equal to 110 percent of the 1929 level, or more than 140 percent of 1935. Using the same assumptions, a return to the 1929 level of *unemployment* by 1937 would require an output equal to 120 percent of 1929, or nearly 55 percent greater than 1935.

Of course neither technological progress in individual industries nor the composition of the total national output will remain unchanged. There is every reason to believe that productivity in individual industries will continue to rise as it has in the past and that the general production level would therefore have to be higher than indicated in order to attain the employment or unemployment levels cited above. On the other hand, a further relative growth of service activities would tend to have the opposite effect since, because of the nature of these activities, they provide more employment per unit of the Nation's net product than the basic industries. In the event of such an expansion of service activities, it is not inconceivable that another productivity plateau similar to that of 1922–29 should result, although on a much higher level.

Although hedged about by many qualifications, these guesses still leave out of consideration many eventualities: Possible changes in the length of the full-time week and many factors which may affect the size of the labor supply, such as farm migration, increased school attendance, child labor, and old-age pension legislation. Yet it seems desirable to hazard these guesses in the interest of focusing attention on problems which are likely to become increasingly important within the next few years.

"Technological Unemployment"

The material presented in the preceding sections served to illustrate one phase of the two-fold character of the relationship between changes in productivity and in employment—the relationship between the vol-

[18] The American Telephone & Telegraph Co. estimates that spreading the work during the depression resulted in the retention of 40,000 employees whose services would otherwise not have been used. *Employee Information Bull. No. 12* (New York Telephone Co.), June 15, 1936.

ume of output, the volume of labor engaged in producing this output, and the size of the labor supply. The other phase concerns the extent to which employees are displaced and occupational readjustment becomes necessary for reemployment.

The preceding discussion contained a number of clues to the extent to which the diverging movements of employment and productivity in various industries must either have necessitated profound adjustments in occupational skills and social and professional status or else resulted in extended or permanent unemployment. In connection with this phase of the problem there are several questions which one should like to be able to answer in quantitative terms: How many workers are displaced, temporarily or permanently, by the introduction of various technological improvements? What is the annual volume of the displacement and the absorption resulting from such improvements? What is the net effect, in terms of job opportunities gained or lost, of changing industrial techniques?

The succeeding pages will have served their purpose if they make clear some of the problems involved and give some inkling of the answers.

Technological Change and Productivity

Except in very rare cases, the effect of strictly technical changes on employment in a single industry or even a single plant cannot be isolated. The productivity ratios presented in the preceding section can be regarded as indicative of the effects of technological change only in the broadest sense.[19] These over-all productivity ratios (quantity output per unit of hired-labor time) reflect a variety of factors in addition to the mechanical improvements usually characterized as "technological." Thus productivity may change as a result of nonmechanical aids to labor, or managerial improvements, or in response to varying degrees of utilization of productive capacity, or changes in the hours of work, or any combination of these and other factors. On the other hand, technological improvements are frequently made without any resulting changes in the productivity ratio, although they may cause changes in the occupational requirements of the industry directly concerned or of a related industry.

In general, it should be kept in mind that, quite apart from the possible direct displacement of workers as a result of the introduction of more efficient machines or better management, a technological improvement or innovation may result in indirect displacement of workers in any or all of the following ways:

(*a*) Diverting production from a competing plant in the same industry.

(*b*) Reducing the output of another industry by offering a cheaper or more effective substitute.

(*c*) Reducing the amount of raw material, fuel, or equipment used by eliminating waste and spoilage.

(*d*) Reducing the amount of labor required in the industries using a given product by improving its quality and efficiency. Improvements in the quality of steel used in machine tools make possible much higher machine speeds and less frequent sharpening, thus reducing the amount of labor required in the industries using such tools. Similarly, improvements in the quality of steel rails reduces the requirements for maintenance, replacement, and repair labor on railroads.

A technological change, however, may also stimulate employment in the same or other industries to such a degree as to offset its displacement effects by the absorption of an equivalent number, though not necessarily the same workers. As indicated in the following pages, there are no data available which would measure adequately the extent to which individual workers are affected by the displacement and absorption effects of technological improvements.

Industrial Displacement

One attempt to throw some light on the problem of individual readjustment is represented by Dr. F. C. Mills' comparison of industrial accession and separation rates in manufacturing industries during the period from 1899 to 1929.[20] Dr. Mills' data relate to accessions and separations from *industries*, not establishments or occupations, and therefore understate the extent of the difficulties which workers face under modern industrial conditions, inasmuch as they throw light only on the more severe type of readjustment which requires the absorption of workers in industries other than those they left, voluntarily or otherwise. Furthermore, since the data refer to the *net change* in each industry between census intervals, they understate by far the extent of the actual turn-over during the period. Dr. Mills found that during each 2-year period, on the average, between 1923 and 1929, 49 men out of every thousand employees withdrew from or were forced out of the industry in which they were working, compared with 21 men out of every thousand during each 5-year interval from 1899 to 1914. He finds it "an impressive fact that under the prosperous industrial conditions prevailing between 1923 and 1929 one individual worker out of 20 was forced, every 2 years, to seek employment in a new

[19] See preceding section on "Over-all productivity" for further explanation of this ratio.

[20] *Economic Tendencies in the United States* (New York: National Bureau of Economic Research, Inc., 1932), pp. 419–23.

manufacturing industry, or in a nonmanufacturing industry. These conditions placed lighter demands upon industry for the training of new men, but placed much heavier demands upon wage earners, and enforced a degree of adaptability not required under pre-war conditions." The following data, indicating the increase in the separation rates for the major groups in the manufacturing industries, are presented by him as "most significant as regards the strain of readjustment placed on wage earners":

Separations of wage earners, by industrial groups, 1899–1914 and 1923–29

Industrial group (manufacturing)	Separations, as percentage of average number employed [1]	
	1899–1914	1923–29
Foods	1.0	2.8
Textiles	1.5	4.8
Products of petroleum and coal	5.0	3.2
Iron and steel	1.5	4.0
Machinery	.2	2.6
Transportation	4.2	11.5

[1] Figures relate to average changes during census intervals. Such intervals were of 5 years' duration during the period 1899–1914 and of 2 years' duration during the period 1923–29. (Adapted from F. C. Mills, *Economic Tendencies in the United States* (New York: National Bureau of Economic Research, Inc., 1932), table 167, p. 423.)

Increasing Productivity and Displacement

Utilizing data on production and employment, and calculating productivity changes, what might be done in the way of measuring displacement? Suppose that in 1 year 100 men were employed in a given industry to produce 100 units of output and that in the next year the use of labor-saving techniques made possible the manufacture of 110 units with only 90 men. Since employment declined by 10 men despite the increase in output, one might conclude that the technological displacement amounted to 10 men. One might also point out that if the new techniques had not been used and production had increased 10 units, 110 men would have been employed instead of the 90 actually at work. On that basis it is possible to state that the increased productivity affected 20 men—10 who actually lost jobs they had held the previous year and 10 who would have been employed but for the increase in productivity. On the other hand, it is equally valid to maintain that if the improved techniques had been put into operation while production amounted to 100 units only 82 men would have been required, indicating a displacement of 18 workers which, however, was offset in part by the actual increase in output requiring the services of 8 more men.

Knowing only, as in the above example, the net change in the volume of output and employment, it is possible to draw three different conclusions as to the displacement effect of improved efficiency. The first cites only the net decline of 10 men as the displacement. The second presents the difference between the number actually working the second year and the number who would have been employed if productivity had not changed. The third suggests as the volume of displacement the difference between the number actually employed the first year and the number who would have been employed if the increased productivity had not been accompanied by an increase in output.

All three figures are useful in examining the net effect of the increased efficiency on the number of available jobs in the industry, but none of them can be said to describe the displacement effects of technological improvements so far as individual workers are concerned, and it is an individual who becomes unemployed. The net change in employment may very well have resulted from the dismissal of, say, 50 workers whose skills were no longer required, and the hiring of 40 others. Only in rare instances would the computed "displacement" figures depict accurately the number of individuals displaced from the industry. Even if any one of the results of these computations were able to describe the effects of the improved efficiency on displacement in this industry, the picture would be far from complete.

The increased production may have required the use of additional raw materials and transportation and distribution facilities, and may thus have resulted in additional employment in these activities, which, if added to the 90 men employed in the manufacturing process may have resulted in a total employment of 100 or 110, or even more, men. If the increased production was attributable to the introduction of improved production methods, it might have been responsible for a net increase in total employment. On the other hand, the increased production may have resulted from the introduction of methods which also made possible a more economical use of raw materials, and the machines may thus have reduced employment not only in the manufacturing process but in the industries supplying and transporting the raw materials required.

To measure the full effect of even a single technological change on displacement and absorption would therefore necessitate the virtually impossible task of tracing it through the innumerable factors which bear on the total volume of production and employment. Making direct inquiry among employers and workers would not be feasible either, since frequently neither the worker who loses his job nor the employer who lays him off knows whether the lay-off is the result of

technological improvements or not. Assume, for example, two factories, A and B, located in different parts of the country and producing the same commodity for sale on the national market. Factory A introduces labor-saving machinery which results in increased productivity and lower costs, making a reduction in price possible. Factory B, which has not introduced the new machines and cannot meet the lower prices of A, fails to get its usual volume of orders and is forced to lay off part of its working force due to "slow" business. While neither the laid-off workers nor the employer may be aware of the situation, the workers were displaced by the introduction of the new machines just as truly as if the machines had been installed in their own plant. Indeed, had the machines been installed in plant B they might have kept their jobs, with the displacement occurring elsewhere. A somewhat analogous situation presents itself when a producer operating a number of plants finds it profitable to modernize several plants, to shut down the least efficient ones, and to continue to produce the same amount of goods as before.

"Unrealized" Employment

The difficulty of tracing the interindustry effects of technological changes may be met in part by treating the entire national economy as a single industry and measuring the net effects of changes in output and productivity. Thus the following question might be asked: How much of any year's unemployment can be ascribed to the difference between the total number of jobs available that year and the number which would have been required for the production of that year's total output had the over-all productivity remained at some previous year's level? Thus, if 100 workers were needed to produce 100 units of production in 1 year and only 79 men were needed to produce 105 units of production in a subsequent year, the labor requirements per unit of production declined from 1 man to 0.75 (productivity increased from 1.00 to 1.33) and the difference between the number of jobs available and the number which would have been available had productivity remained at the earlier level is equal to 26. These 26 jobs consist of 21 jobs which had previously existed and were eliminated by the increase in productivity, and 5 additional "jobs" which would have become available but for that same increase in productivity. One may therefore conclude that, if there are 26 unemployed workers, they may be said to be unemployed due to increased productivity; and that, if there are 50 unemployed workers, 26 of them may be said to be unemployed due to increases in productivity. On the other hand, if there are fewer than 26 unemployed workers, all of them could be designated as unemployed because of increases in productivity.[21]

A little reflection will make it clear that if one chooses the "previous level of productivity" with which to make the comparison in a period sufficiently far in the past, one might find that the difference between the "number of jobs which would have been available" and the number actually available is greater than the total number of unemployed; it might even be in excess of the total available labor supply, if the increases in productivity and production were extremely large. These results reflect the assumption, inherent in the method outlined, that the volume of production is independent of technological progress. The fact is, however, that the volume of goods and services could not possibly have increased at the rate at which it has grown without the technological improvements which have taken place.

If the periods chosen for comparison are relatively close, however, say 2 successive years, the error resulting from an assumption of independence between changes in productivity and the volume of production is held to a minimum. Accepting such a degree of independence as a working assumption, the question can be rephrased as follows: How much of any year's unemployment may be ascribed to the difference between the number of jobs available that year and the number which would have been required for the production of that year's output had the productivity remained at the level of the year *immediately preceding* it?[22]

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[21] The following data were presented in this example:

	First year	Second year
Number of units produced	100	105
Productivity	1.00	1.33
Labor required per unit produced	1.00	.75
Jobs:		
Number actually available	100	79
Number which would have been available had productivity remained unchanged	100	105
Difference in number available		26

[22] Other questions could be presented and answered in statistical terms. Professor Harry Jerome, for instance, has formulated four different questions, each of which is subject to a quantitative answer: "How much less labor did it require to produce the current output than would be required at the productivity rate of the base year? * * * How much less labor would be required to produce the base-year output at the current productivity rate than actually was required at the base-year productivity rate? * * * What is the cumulative constructive displacement when the displacement for each year is computed by multiplying the current year output by the differential between the labor requirement ratios of the current and the immediately preceding year? * * * What is the cumulative constructive displacement when the displacement for each year is computed by multiplying the output of the preceding year by the differential between the labor requirement ratios of the current and the immediately preceding year?" *Mechanization in Industry* (New York: National Bureau of Economic Research, 1934), pp. 377–378.

A number of surveys have been made by the U. S. Bureau of Labor Statistics to determine the extent of "technological displacement" in specific industries, answering either the first or the sec-

If the material on total production and total employment, presented earlier in this chapter, is subjected to the measurement implied in this question, it is possible to calculate the number of man-years which would have been employed each year had productivity remained at the level of the year immediately preceding. The difference between this number and the number of man-years actually employed may be referred to as "unrealized" employment. The estimates shown in table 9 indicate the volume of "unrealized" employment as a proportion of the unemployed manpower which might have been used each year if productivity had remained at the preceding year's level and production had not been affected thereby. Thus, had productivity remained in 1921 at the level of 1920, the volume of output produced in 1921 might have required the employment of a volume of additional man-years equal to over one-third of the manpower unemployed in 1921. In 1922, nearly 50 percent of that year's unemployed manpower might have been used had productivity remained at the 1921 level (assuming what could hardly have occurred—that production would have increased without the change in productivity). In 1933 over 13 percent of that year's unemployed manpower might have been put to work but for the rise in productivity over the preceding year. Expressed in terms of each year's employment, "unrealized" employment in 1933 was virtually the same as in 1921 and 1922, although it constituted a much smaller proportion of the total unemployed manpower. During the period surveyed, except for the period after 1929, when the sharp decline in output resulted in a tremendous increase in unemployment, "unrealized" employment constituted from one-fifth to one-half of the unemployed manpower in the years when over-all productivity increased.

It should be kept in mind that, inasmuch as these calculations were performed on the basis of the over-all figures of production, employment, and productivity, all of the qualifications which were previously applied, both with respect to the concepts and the quality of the data, apply to an even greater degree to the figures on "unrealized" employment. It must be remembered further that, for the various reasons discussed earlier these figures do not constitute measures of the number of "technologically unemployed" workers.

TABLE 9.—*Estimates of "unrealized" employment, based on year-to-year increases in productivity, 1920–35*

Year	Man-years of actual employment [1] (1920=100)	Man-years of possible employment if productivity had remained at the level of the preceding year [2]	Man-years of "unrealized" employment as percent of—		
			Employment in 1920 [3]	Each year's employment [4]	Each year's unemployment [5]
(1)	(2)	(3)	(4)	(5)	(6)
1920	100	n. a.	n. a.	n. a.	n. a.
1921	81	90	9	11	34
1922	87	99	12	14	49
1923	102	96	(*)	(*)	(*)
1924	101	104	3	3	19
1925	104	107	3	3	19
1926	108	105	(*)	(*)	(*)
1927	110	109	(*)	(*)	(*)
1928	111	116	5	5	33
1929	116	114	(*)	(*)	(*)
1930	106	99	(*)	(*)	(*)
1931	90	92	2	2	4
1932	73	73	(*)	(*)	(*)
1933	72	80	8	12	14
1934	79	79	(*)	(*)	(*)
1935 [6]	82	85	3	4	5

[1] Same as column (5), table 2.

[2] Obtained by multiplying the index of actual employment for the preceding year by the percentage each year's production is of the preceding year. The resulting figure represents the volume of employment if productivity had remained at the level of the preceding year. (As percent of actual employment in 1920.)

[3] Column (3) less column (2).

[4] Column (4) divided by column (2).

[5] Unemployment obtained from table 2.

[6] Preliminary.

*No "unrealized" employment: productivity declined or was unchanged.

n. a. Not available.

Summary

No satisfactory method of measuring the effect of technological changes on employment has yet been evolved. The complexity of the interrelationships between industries and between productivity and production makes impossible an adequate quantitative description of the full effects of technological developments.

In view, however, of the number and variety of changes in industrial techniques during the twenties and the substantial volume of unemployment during the same period, it is reasonable to conclude that in any given year a considerable proportion of the unemployed consisted of workers who had been displaced in the various ways indicated earlier in this section. This conclusion is supported by the added circumstance that the skills and other employment qualifications required in the expanding service industries differ considerably from those possessed by workers displaced in those basic industries where increased

ond question listed above. Some of these may be found in the Monthly Labor Review, October and December, 1931, and February, March, April, and October, 1932. Estimates based on the year-to-year changes have been less frequently made. Two such computations have been made by the Bureau of Labor Statistics for the rubber tire and the electric lamp industries: Boris Stern, Labor Productivity in the Automobile Tire Industry (U. S. Bureau of Labor Statistics Bull. No. 585, 1933); and Witt Bowden, Technological Changes and Employment in the Electric-Lamp Industry (U. S. Bureau of Labor Statistics Bull. No. 593, 1933). Estimates for manufacturing, steam railroads, and coal mining were presented by David Weintraub in "The Displacement of Workers Through Increases in Efficiency and Their Absorption by Industry, 1920–31," Journal of the American Statistical Association, XXVII, No. 180 (1932), 391.

productivity was accompanied by declining employment. Further substance is given to this surmise by the fact that the estimated unemployment for a "good" year like 1929, being based on the Census of Occupations concept of "gainful persons", includes only workers who had been previously employed. Aside from those whose unemployment was of a seasonal nature, a substantial proportion of these unemployed workers with "usual" occupations is likely to have consisted of those who were forced either out of industries the labor requirements of which had been reduced or changed or out of industries whose declining production was attributable to technological changes in other fields.

What Happens to Displaced Workers?

A number of questions come to mind in connection with the problem of determining what happens to the worker who has actually been displaced because of technological improvements. Does he have difficulty in securing a new job? How long does it take? Does the new job pay more or less than the old one? Is the new job likely to be in an entirely different industry, or elsewhere in the same one? What factors affect the ease of getting a new job?

A number of studies made at various times throw a little light on these questions. Unfortunately, many of these studies have been made under depression conditions, so that the results are hardly typical of what happens in periods of expansion. Likewise, few confine themselves to "technologically displaced" workers. In addition, these studies are still so few in number that valid generalizations cannot readily be made. The results of these studies, however, taken separately and with due consideration of their individual limitations, do give us an idea of the answers to at least some of the questions raised.

Duration of Unemployment

In 1930 Ewan Clague and Walter J. Couper [23] studied the experiences of 1,190 rubber workers in New Haven and Hartford who had been displaced by shutdowns in 1929 occasioned by the shift of production to more efficient plants. This study revealed that, at the close of 11 months, 13 percent of the workers were still unemployed. Of those finding work, about 61 percent were reemployed at the end of 2 months. The average time lost was about 4.3 months. Only 19 percent of those placed succeeded in finding jobs that paid as well as their former jobs. Fully two-thirds were earning less than before. In some cases losses were as high as 50 and 60 percent of previous weekly earnings. Annual earnings, when expressed as percentages of the incomes in 1928 (the year before dismissal), were found to have fallen almost 50 percent.

In a study conducted by Isador Lubin [24] in three industrial cities in 1928, it was found that, out of a group of 754 men who had lost their jobs within the preceding year, 45 percent were still unemployed. These workers had been displaced for a variety of reasons. Some were displaced as a result of the introduction of technological improvements, others as a result of curtailed production, and still others because the plants moved to other parts of the country.

Almost one-half of those still unemployed had been out for 6 months or more, 18 percent for 9 months or more, and 8 percent for 1 year or more. Of those who succeeded in getting jobs, the majority had been out for more than 3 months. Almost one-half of the reemployed workers had incurred losses in earnings. Fewer than one-fifth found better-paying jobs.

R. J. Myers' study [25] of 370 Chicago men's clothing cutters, displaced over the period from 1919 to 1926 as a result of changes in the organization of the manufacturing process caused by the mass production of popular-priced clothing, disclosed that 7 percent had found no work at all as late as 1928. Less than one-third of those who sought work were reemployed immediately and almost one-half were out for 4 months or more. The average time lost was 5.6 months. One group of cutters, some 236 in all, who had been paid a dismissal wage, lost an average of 5 months. The wages of 30 percent of the entire reemployment group showed increases over their previous earnings, while almost one-half showed reductions.

Katherine DuPré Lumpkin [26] conducted a study of the adjustments made by displaced workers in the depression period. Miss Lumpkin studied shut-downs in 98 manufacturing plants in three counties in the Connecticut Valley between 1929 and 1933. Four industries—textiles, metals, foods, and paper—accounted for 54 percent of the shut-down establishments and more than 80 percent of the displaced workers. Most of the plants either moved to the South or other parts of New England or were merged with other plants. She made a detailed analysis of some 300 displaced textile workers in one of these communities and found that well over one-half of the workers she was able to trace were still unemployed in 1934. Since all of these workers were not dismissed at the same time, however, some of them had been out relatively short periods of time when the reports were made. Of those reem-

[23] "The Readjustment of Industrial Workers Displaced by Two Plant Shutdowns", After the Shutdown (New Haven: Yale University Press, 1934), pt. I.

[24] The Absorption of the Unemployed by American Industry (Washington, D. C.: Brookings Institution, 1929).

[25] Occupational Readjustments of Displaced Skilled Workers, Journal of Political Economy, XXXVII, no. 4 (August 1919), 473–89.

[26] Shutdowns in the Connecticut Valley, Smith College Studies in History, vol. XIX, nos. 3 and 4 (April and July 1934).

ployed, only 11 percent reported increases, and fully three-quarters reported decreases, in full-time weekly earnings. A few of the losses reported were as high as 70 percent or more. Skilled workers were forced to resort to jobs requiring less skill and paying lower wages.

Several other studies of unemployed workers and of applicants for employment throw some light on the duration of unemployment in "good" years. To be sure, the workers surveyed did not consist specifically of those displaced by technological improvements, but the results are nevertheless of some significance in that connection.

A survey made in Philadelphia in April 1929, by F. D. Dewhurst and Ernest A. Tupper [27] showed that about 10 percent of the employable persons were then totally unemployed. About one-half of these had been out of work for more than 3 months, between one-third and one-quarter for more than 6 months, and one-tenth for more than 1 year. This is an indication of the relative difficulty of obtaining work (in a large and diversified labor market) even in 1928 and 1929.

A study, made in 1929, by Burton R. Morley,[28] of applicants for work at 39 Philadelphia establishments showed that one-half had been unemployed for 1 month or more, one-quarter had been out of work for 2 months or more, one-tenth for more than 4 months, 5 percent for more than 6 months, and 2 percent for 1 year or more.

Factors of Age, Skill, and Sex

E. Wight Bakke's study,[29] which followed the displaced Hartford rubber workers through the first 3 years of the depression, showed that the skilled workers lost 4.8 months in the first year. In that same year the unskilled lost only 4.6 months. The annual incomes of the former group fell to 50 percent of the 1928 incomes, the latter to 62 percent. In the first year the incomes of the skilled workers declined 28 percent more than those of the unskilled. In the third year following the shut-down, not only were the relative losses of the skilled greater than those of the unskilled, but the absolute average annual incomes were lower. As Dr. Bakke points out, "apparently the qualities which helped men to rise to skilled jobs and high wages *while at work* are of limited use in helping men to readjust satisfactorily *when the job goes*." [30]

[27] Social and Economic Character of Unemployment in Philadelphia, April 1929 (U. S. Bureau of Labor Statistics Bull. No. 520, 1930).

[28] Occupational Experience of Applicants for Work in Philadelphia (University of Pennsylvania, 1930).

[29] "Former L. Candee Workers in the Depression", After the Shutdown (New Haven: Yale University Press, 1934), pt. II.

[30] *Ibid.*, p. 111.

Women were placed more quickly than men, although their incomes suffered more. Clague and Couper found that, after 11 months, 77 percent of the women and only 70 percent of the men had been reemployed. Of these, 64 percent of the women and 61 percent of the men had been placed within 2 months. But among those who were placed, almost one-third of the men and only one-fourth of the women found jobs in which their wage rates were as high as they had been in 1928 before they lost their jobs. The average weekly earnings expressed as percentages of the 1928 earnings fell to 76 percent for women and 80 percent for men. Declines in annual incomes showed a very small difference between the sexes, with the women losing slightly more than the men. Incomes of men fell to 58 percent of the 1928 level and of women to 55 percent.

Clague and Couper found that, at the end of 11 months, 73 percent of those under 25 years of age, 84 percent of those between 25 and 35, 73 percent of those between 35 and 45, and 61 percent of those over 45 had been reemployed. Only 61 percent of all the workers had been placed within 2 months. It was also found that 23 percent of all the workers who were reemployed were paid wages as high as or higher than before. Some 31 percent of the workers under 25 years of age were in this group while in the older groups the percentages were considerably under the average. Earnings, expressed as percentages of the 1928 level, were 92 percent for workers under 25 years of age, 80 percent for the group between the ages of 25 and 35, 71 percent for those 35 to 45, and 78 percent for those over 45.

Lubin found that of those getting jobs the group falling between the ages of 35 and 45 fared best, 65 percent finding jobs.

The study made by Katherine Lumpkin showed that, following the shutdown, those under 25 years of age were unemployed 80 percent of the time during the years that followed; those between the ages of 25 and 35 were unemployed 72 percent of the time; those 35 to 45, 75 percent; and those over 45, 87 percent.

Absorption in Other Occupations and Industries

In answer to questions concerning the occupations and the industries into which the workers were reabsorbed, Lubin's figures showed that fewer than 1 in 10 went back to their old work and that altogether only 33 percent were reemployed in industries producing goods similar to those produced in their old jobs.

Myer's figures revealed that by early summer of 1928 only 20 percent of the Chicago cutters displaced between 1919 and 1926 had gone back to their trade. All others who obtained work found it in a variety of employments, most of which had no connection with

either their former skill or their former industry. Only 7 percent of these highly skilled craftsmen found any kind of skilled work other than cutting.

As for the absorption of the displaced workers by the so-called "new" industries—personal service, automobile and related activities, radio, motion pictures, and hotels and restaurants—Lubin's study showed that, although there were some reabsorptions into the "new" industries, they were not very numerous. Only 53 of the 410, or 13 percent, were absorbed by them. Of these, the largest proportion entered occupations associated with the automobile: as chauffeurs, garage and filling station attendants, and allied occupations.

Following their lay-off, some workers set themselves up in business. About one-fifth of the Chicago cutters and 18 of the 423 interviewed rubber workers, or 3 percent, became small entrepreneurs. Of the latter group, only five were successful; eight were discouraged, and five failed, losing $300 to $600. On the whole they fared badly because they had little of the necessary training and even less of the requisite capital.

Most of the unemployed Philadelphia workers studied by Morley in 1929 had long, steady, and satisfactory past employment records. Fully two-thirds had held only two jobs since 1926; 87 percent had held only three jobs in that period. About one-third had made no job changes at all since 1926. Many of the jobs had been held for much longer than 3 years. Most of these, clearly, were workers whose services had been satisfactory and whose loss of jobs was through no fault of their own. This study showed, further, that very few of the workers had come from other communities in search of jobs. Fully 80 percent of those seeking employment in Philadelphia had been employed there before dismissal, and fully 94 percent formerly had jobs within a radius of 100 miles. There was, however, a considerable amount of occupational mobility. Over 70 percent of the workers holding more than one job since 1926 had held them in more than one industry. Only 21 percent of those holding three jobs had remained in the same industry.

In general, technological improvements which substituted new processes for old have meant the displacement of workers whose special skill and training were no longer needed. In some few cases, generally because a training period at the employer's expense is necessary anyhow, efforts had been made to retrain old workers and to fit them into the new jobs. At least one company manufacturing automobile bodies is known to have made successful use of this technique. Over the period from 1932 to 1935, this company shifted from the manufacture of composite auto bodies containing lumber to all-steel bodies. The company offered to train and transfer all of the affected woodworkers to any of the metal crafts that they chose. During the period of training they were guaranteed a minimum wage. Following the training period, they became part of a gang and like the rest of the gang were paid on a piece-rate basis. Workers who failed at the crafts of their own choosing were transferred to any of the eight other crafts. No worker was "fired" unless he had failed in all crafts. Fully 99 percent of these transfers were successful. The estimated cost of this training was about $50 per worker, or about $15,000 in all.[31]

Summary

As was indicated at the beginning of this section, the material available concerning the question of what happens to workers who are displaced as the result of changing industrial techniques is very scattered and inconclusive. Only three of the studies described deal specifically with "technologically displaced" workers (Clague-Couper-Bakke, Myers, and Lubin); one deals with the experiences of workers displaced during the depression (Lumpkin); one deals with the workers displaced immediately prior to the depression and analyzes their experiences during 1929 (Clague-Couper) and during the first 3 years of the depression (Bakke); only two studies (Lubin and Myers) cover workers displaced prior to 1929, but both of these cover only male workers and one of them is concerned only with highly skilled workers (Myers).

There is a certain amount of agreement in the findings of the studies covering the displacement of workers in the larger communities, that is, communities offering a fair degree of diversification in employment opportunities. Thus, in almost every instance, it was found that the unskilled and the younger workers (under 25 years of age), who had comparatively little to lose, lost less in terms of occupational status and earnings than the skilled workers; the middle-aged group, ranging in age from 35 to 45, found it easier to obtain suitable employment than the older workers; the women found it easier to find jobs than the men but got poorer ones; the majority of the workers who found jobs found them in industries and occupations other than those in which they had been previously employed.

A great deal more should be known about the experiences of both employed and unemployed workers in different types of employment and unemployment situations and in different parts of the country. Much more information is needed concerning the source of the labor supply in expanding occupations and the "new" industries. More needs to be known about the mobility of labor in connection with the migration of industries, and about the effect of mobil-

[31] H. H. Seaman, Woodworkers are Welders Now, Factory Management and Maintenance, XCIII, no. 9 (September 1935), 365–366.

ity on communities which such migration often leaves "stranded." Information is needed concerning the degree of success with which retraining of workers from one skilled occupation to another may be accomplished. More knowledge is wanted on the subject of the similarities in the character of skills required by different and seemingly unrelated occupations. The National Research Project of the Works Progress Administration is attempting to find the answer to some of these questions through a series of special studies designed to throw more light on these problems. They must be thoroughly understood if proper measures are to be taken for the amelioration of the lot of those workers who find themselves without a source of income as a result of industrial, economic, and social change.

Conclusions

It was not the purpose of the foregoing discussion to examine in detail the inner workings of the various economic forces which reflect themselves in the fluctuations of the volume of production, employment, and unemployment, nor was it intended to evolve a new and all-embracing "theory of technological unemployment." This subject has been receiving extensive treatment since the beginnings of the industrial revolution; probably all of the theories, causes, and remedies now under discussion have been advanced at one time or another during the past one hundred years.

Interestingly enough, the remedies which are now most popularly advanced are also among the oldest. J. B. Say, who in the early nineteenth century was among the first to present a considered discussion of the effect of the introduction of new machines, advocated public intervention to consist of "restricting in the beginning the use of a new machine to certain districts where labor is scarce or required by other industries * * * providing in advance for the employment of the idle by undertaking at its own expense works of public utility, such as a canal, a highway, a big building * * * promoting a transfer of population from one locality to another." In later editions of his works, the first suggestion was dropped on the ground that such intervention would "violate the property of the inventors."[32] The suggestion for public works, however, was retained.

Since the days of Say there have been few outstanding economists who have held that technological advances result in no employment dislocations whatever. Most economists have recognized the possibility or likelihood of temporary dislocations and displacement of workers as a result of improvements in production techniques; some have even advanced claims for the possibility of permanent unemployment and the creation of a "surplus population." Many of the economists concerned themselves primarily with the problem of the marketability of the increased production made possible by changing techniques. Others have interested themselves in the relationships between the volume of accumulated capital and the volume of employment it is capable of providing. Still others have devoted their attention to the disproportion between consumption and investment. Many of the writers who have emphasized one or the other of these factors have at the same time been concerned with the "frictions" and "rigidities" of the economic system which in one way or another prevent the smooth working-out of the particular theory advanced. The emphasis on the frictional elements is especially marked in the more recent literature dealing with the subject.

The current thinking of many economists concerning the problem under consideration is perhaps most adequately represented by J. M. Clark. In his recent work, Economics of Planning Public Works, [33] Professor Clark indicates that material progress and increased output per worker may "create dislocations in our economic system because we cannot make the necessary adjustments fast enough." There is not sufficient evidence, in his opinion, to prove that these dislocations must take place, but there are *prima facie* grounds for believing that they do. Lacking the necessary adjustment, "mere technical progress seems capable * * * of bringing on a state of chronic inability to use all our labor power."

In considering employment in the depression and the possibilities of a return to 1929 conditions, Clark stated: "Improvements have been made since 1929, enabling a given output to be produced with less labor, and many more probably stand ready for introduction when confidence revives sufficiently and when the condition of the capital market makes it possible to raise the necessary funds. Thus, unless there is a shortening of hours in industry * * * there may be a considerable amount of unemployment even after the current revival has gone as far as it can." He concludes that "among the possibilities which we may have to meet * * * are conditions of unemployment lasting a great deal longer than cyclical depressions or temporary emergencies produced by outside causes."

Although the material presented in the foregoing sections of this chapter cannot be used either to affirm or deny any particular theory advanced, it does permit some tentative observations.

[32] Traité d' économie politique (2d ed., 1814), 1, 55n.

[33] A study made for the National Planning Board of the Federal Emergency Administration of Public Works and printed by the U. S. Government Printing Office, 1935. See especially ch. IV from which the quotations in the text are taken.

The problem of "technological unemployment" is essentially twofold: One, the expansion of total production sufficiently to overcome the effect on unemployment of declining labor requirements and increasing labor supply; and two, adjustment of the individual employment dislocations which accompany technological progress.

The growth in total output from 1920 to 1929 was not sufficient, in the light of the increased productivity and the growth of the labor supply, to absorb all the available manpower; the result was a substantial volume of unemployment during this entire period. The data examined indicate that, while the continued advance in the material well-being of the country depends upon technological progress of the country's productive apparatus, we must look to a much more rapid expansion of production than has taken place between 1933 and 1935 before we can expect a return either to the employment or to the unemployment levels of the predepression period. A rough calculation indicates that, in order for unemployment to drop to the 1929 level by 1937, goods and services produced would have to reach a point 20 percent higher than that in 1929, even if the productivity level of 1935 remained unchanged. Further technological advances in industries would necessitate an even greater expansion of production to restore predepression unemployment levels, while a continued relative growth of service activities would tend to minimize the volume of expansion required.

An undetermined but substantial proportion of the unemployed in any single year probably consisted of workers who had been displaced from their jobs in one way or another by the employment dislocations which accompany technological progress. The notable expansion in employment which took place between 1920 and 1929 was due almost entirely to the rapid growth of service activities; their occupational requirements differed so widely from those of the basic industries which registered declines that it is extremely unlikely that all the workers displaced from basic industries obtained new jobs in the service industries.

Such material as is available on the question of adjustment of displaced workers indicates that the unskilled and younger workers lost less in occupational status and earnings (since they had less to lose) than the skilled workers; the middle-aged group found it easier to obtain suitable reemployment than the older workers; women found it easier to obtain jobs than the men, but suffered greater income losses; the workers who did find jobs found them chiefly in occupations and industries other than those in which they had previously worked.

The outlook for the immediate future seems to be in the direction of further technological progress toward a level of productivity substantially higher than that attained prior to 1929. The rate of advance of course differs in different industries, but since our economic system has not evinced an ability to make the necessary adjustments fast enough, it may be expected that the dislocations occasioned by technological progress will continue to present serious problems of industrial, economic, and social readjustment.

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PART TWO
SCIENCE AND TECHNOLOGY

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I. THE RELATION OF SCIENCE TO TECHNOLOGICAL TRENDS

By John C. Merriam [1]

Justification of a planning program in technology, as in other subjects, may arise from recognition of continuing change either as indicated in past records or in the conditions of any given time. If accurate prediction of future situations were possible, it would be important to plan the adjustment of flexible elements in all activities to conditions of the future. If precise forecasting is not feasible, forward-looking plans would still be desirable, as furnishing means for quick adaptation in order either to avoid cataclysmic changes or to carry out constructive programs. The extent to which effective planning is possible will depend upon the accuracy of our knowledge concerning both individual features and the laws expressed in changes known to have taken place.

Modification in what we call the result or contribution of technology as illustrated in industry sometimes occurs so quickly that it produces disturbing social influences. If such shifts could be foreseen, many difficulties would be avoided. If they cannot be predicted, it may still be possible to understand the circumstances sufficiently to avoid unfortunate effects if precautionary measures are taken.

The relation of science to technology has become increasingly important as the products of research come to have a more significant place in industry. In development of this relation connecting science and technology and industry, the responsibility of science to the contribution of technology is evident. But commonly the relation of science to industry and technology is only in part direct; generally it is the application of inventive genius in utilization of results coming from research that brings about the rapidly developing series of changes in engineering and industry.

The importance of the relation of science to technology and to industry depends in considerable part upon the expectation of changes in science which may affect technology and influence industry or even the general trend of thought. If we were known to be dealing with a static world in which our knowledge regarding all available materials and of man was approximately complete, it would be possible to formulate plans which, with slight variation, might operate almost indefinitely. It is, however, clear that by whatever means we view the history of science and research we are seen to be dealing with almost continuously changing conditions to which adjustment must be made. Activities coming out of the growth of science have given us means for new development of transportation, geographic discovery, communication, and a multitude of other things, perhaps culminating in the automobile and the radio of the present day. A relatively large percentage of these recent advances has arisen from the contribution of science carried to application by engineering. A critical question in discussion of this subject concerns the expectation of a continuing supply of new knowledge from science which may lead to technology and industry.

We may perhaps set down as one of the most important contributions from modern science and research the suggestion that we are probably very far from having a complete knowledge of anything in the world of physical, biological, or human values. In the universe of things physical alone, very great advances have been made within the last generation in our knowledge of materials, forces, and conditions encountered on all sides in everyday life. In biology the degree of complication is still greater, and investigators generally hold that we are just beginning to understand fundamental life conditions and processes.

To those acquainted with the development of science there is little difficulty in accepting the suggestion that our knowledge of nature and man will increase greatly with the coming centuries. It is also to be expected that human constructive activity will bring about the creation of conditions and relationships which have not previously existed. If this suggestion be accepted, development of any planning program of national scope must take into consideration the significance of these new factors in bringing about readjustment. While it is not possible to predict the direction which such changes will take, or the specific fields in which discoveries, inventions, or new creative activities may express themselves, it would be unfortunate if these possibilities were neglected in a general planning program.

It is essential also that a planning program give attention to study of the actual applications being made of values derived from research in its various forms. Organization of means by which results of science already available or arising through new discoveries could come into human use might mean an enormous contribution to betterment of conditions for life.

The law of survival of the fittest would ultimately care for new materials and new ideas. But our knowl-

[1] President, Carnegie Institute of Washington.

edge of evolutionary processes over the ages indicates clearly that intelligent grouping or cooperation or guidance, without the necessity of absolute restraint, may bring about relatively favorable conditions, and in a shorter time than is possible through influence of the law of survival of the fittest or the fight for existence. It is a part of the responsibility of an intelligent people to consider values which it creates and their relation to other values. It is doubtful whether long range planning activity can perform a more important service than that which may be contributed through study of possible situations in this field.

Further study of all programs relating to protection given by patents may aid in discussion of this question. In accepting responsibility for adjustment to advances through discovery and invention, it is possible to plan a program of patenting which would consider public interest to a larger extent in directions where such interest needs protection.

The means by which adequate balance can be established among the interests and contributions of science leading into technology and industry, and the elements arising out of studies on social, economic, and governmental questions cannot be determined through the thought of a moment only. They represent some of the most difficult among all human problems. They involve on one hand the possibility of high development of specialized knowledge and, on the other, the organization of society for mutual benefit. The spread between the highest expression of these types of interests is wide. But there is an intermediate position which must be found in order to secure the benefits of all.

From a number of directions we have the suggestion that for guidance in development of new ideas, and for the protection of society, it is desirable to set up types of organization which may bring together scientists, engineers, and forward-looking students of social and economic problems with a view to keeping close watch upon related problems in these several fields. The finding of something like common viewpoints for investigators in different subjects may be difficult, but it will have increasing importance. Such an activity might be established in the hope of fitting new ideas and new techniques to advancing industries and to new phases of social and economic endeavor. If developed guardedly, such a forward-looking program presumably would not hinder the advance of civilization, and might be expected to aid in adjustment of human groups to some of the changes which inevitably take place.

It is important to note that a responsibility for keeping in view the possibility of social influences arising from use of scientific techniques rests in part upon the scientist. Assuming that there will be an uneven movement in the economic-social stream, there is value in having those best acquainted with the nature of new materials and new activities keep in mind the fact that they, as the source of such influences, should have some acquaintance with ultimate application of their products. At the same time it must be realized that unwise use may be due to factors of social significance with which the student of social problems should plan to keep close acquaintance.

In following the implications of these questions it is, among other things, important to examine the idea that scientific methods may function as techniques, which in various ways influence modes of thought and even concern aspects of judgment. If science exerts this influence, it is essential that its contribution be guarded with the greatest care as to its use in education, and also watched by the ablest students as to the manner in which it may affect or guide thought. As one possible influence of science upon thought, we may assume that if the minds of all citizens could be so informed and trained that as a rule there would be insistence upon having and using the elements of fact and reality, which are the basis of science and research, there would be guaranteed a relatively safer situation with reference to the handling of all human problems than has commonly obtained.

II. THE INTERDEPENDENCE OF SCIENCE AND TECHNOLOGY

By Edward C. Elliott [1]

It is erroneous to believe that a new industrial achievement, based on inventive research work and on technical development, must necessarily be the result of an inventive idea. It is quite possible that the economic necessity to produce a material not only inspires the inventor but actually leads to the invention. We, therefore, have to distinguish between inventions resulting from strictly scientific research work and inventions which are, so to speak, made to order. (Friedrich Bergius, general director, Deutsche-Bergin, A.-G., before the American Chemical Society, Pittsburgh, 1936.)

As one takes a long-range view of the many modern forms of productive human activity, to which the term "technology" is applied, one cannot fail to see the conspicuous influence of science thereon. This is a commonplace of contemporary thought. Yet there is an inclination to overlook one aspect of the relation of scientific research to modern industry. That is the modification of science itself through the procedures of industrial development. Consequently any dependable formula of planning for the future will include the recognition of the increasing interdependence of scientific research and that complex economic agency called industry. Such interdependence is obvious as to those fields of applied science commonly classified as industrial research. On the other hand, the contributions to pure science coming from the search for new and more effective industrial processes may not be disregarded in any well-balanced planning scheme. In the world ahead, industry more and more will make use of the results of disinterested science. Likewise, more and more, industry will provide compensating contributions to the nature and the nurture of scientific concepts.

It is natural that an industrial organization whose existence can be traced to discoveries in pure science continues to be interested in promoting further investigations in its own field. Therefore, it is not surprising to observe companies such as du Pont, Carbide and Carbon Chemicals Corporation, General Electric, and Bell Telephone, carrying out purely scientific experimentation of the highest quality in their own laboratories. If a specific example were needed to illustrate the scientific importance of such research it would suffice to mention Langmuir's contributions to the chemistry of surfaces which have resulted in a Nobel laureate.

[1] President Purdue University.

The fact that this policy has not been more widely adopted has doubtless been in part due to the shortsightedness of certain executives, particularly those of old, well-established industries, who were either skeptical of the value to their company of research in pure science, or were frankly unwilling to foster revolutionary advances. It should be said, however, that the one thing which may confidently be expected of research in pure science of the future is that its applications will be unexpected. They are quite as apt to benefit some other industry as the one which initiated them. It is largely for this reason that small companies are, in general, not so likely to support this type of investigation as are large groups of affiliated corporations with activities covering a wide range of interests, and which consequently have a greater probability of benefiting from an unexpected discovery.

In addition to the pursuit of pure science within corporate laboratories, there has been much direct subsidization of university research. The distinction between pure and applied science is at best an artificial one and the celerity with which a given fact, theory, or material will pass from the former to the latter category is a commonplace among scientists. Many research problems are not only of fundamental importance scientifically, but it is obvious that their successful solution would be of real or potential benefit to industry. The question of the mechanism of chemical catalysis is an example of a fascinating scientific problem, the elucidation of which would not only be a scientific achievement of the first order but would also be of immense economic value. It is this type of investigation which has most frequently been carried on in universities as the result of industrial fellowships. The du Pont Co. and the Eli Lilly Co. have established a considerable number of university fellowships without any restrictions on the problem to be studied except that it should be in the general field of organic chemistry.

The indirect effect of industrial research upon pure science investigations in the universities is much greater than that of the fellowships previously mentioned. The bulk of university scientific work is carried out in the various graduate schools as a part of the professional training of young scientists. The majority of these men and women find employment somewhere in our elaborate technological structure. Whether the

professor desires it or not, there is inevitably a strong preference upon the part of young men and women for study in those scientific curricula the graduates of which are demanded by industry. The great expansion of organic and physical chemistry in this country during the past two decades has been in response to a very definite commercial demand which has thus influenced the development of those sciences as surely as though by direct financial subsidization.

Another mode in which technology has been of tremendous benefit to pure scientific research is in the development of novel apparatus and materials for performing tasks which previously could be done inefficiently, or not at all. Precision balances, compound microscopes, reagent grade chemicals, micrometer calipers, thermionic tubes, and scientific glassware are so commonplace that we are apt to forget that we owe them, at least in their present form, to technological development to meet industrial demands. The Podbielniak apparatus for precise laboratory fractional distillation, which has made possible a new degree of accuracy in aliphatic chemistry, was developed as a result of a patent litigation!

The motives which cause certain men and women to engage in the strenuous and exacting toil of scientific research are numerous. One such motive, far from inappreciable in its effect upon many scientists, is the conscious or subconscious desire to control the forces of nature for human ends. The far-flung effects of this control and of these ends upon national planning have been tersely expressed recently by the British scientist, Sir William Bragg—"Pure science, that which I have referred to as long distance science, is international. At a scientific conference nationality disappears. It is when the results of science are incorporated into business and trade that trouble begins."

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TECHNOLOGY IN VARIOUS FIELDS

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I. AGRICULTURE

By S. H. McCrory, R. F. Hendrickson and Committee [1]

Introduction

Few industries are influenced by as many and varied technologies as agriculture. These technologies are, of course, unequal in influence. Similarly, the numerous branches and types of agriculture represented in this country are very uneven in their responsiveness to technologies.

To forecast scientific discovery, mechanical invention, or the rise of new methods is a hazardous undertaking. To weigh their probable influence is infinitely more hazardous. It is evident that the effects of many technological developments long known and widely applied in farming have escaped accurate measurement.

All this has been recognized in this effort to indicate future trends in technology as they may affect agriculture. Because of the large variety of technologies which bear on agriculture, specialists in fields which have contributed greatly to technological change in agriculture—fields in which there is reasonable expectation for further advance—have been invited to indicate avenues of promise. They have been asked to relate these to past and, especially, to recently erected milestones of discovery so as to assist in throwing light on economic and social implications of developments ahead.

Men are not possessed of equal amounts of hope and caution. The sections of this chapter which follow reflect this factor of human variability. Some contributors may prove to have been too optimistic with regard to both future developments and their implications; others are doubtless cautious to an extent that will be handicapping to persons who are anxious to anticipate future technologies with a view to preparing for them.

It should not be inferred that technological change affecting agriculture is limited to fields dealt with here. Such a view would be as unwarranted as opinions that new discoveries, inventions, and techniques will come only in the formalized areas of investigation—or only from those who are seeking them.

I. TECHNOLOGY: ITS ADVANCE AND IMPLICATIONS

The productivity of the average worker in agriculture has been stepped up greatly in the past 100 years and this trend promises to continue. The rate of the increase has been almost steadily rising. If this continues to be the trend numerous adjustments will be necessary in the future. And these adjustments will mean social and economic change as surely as the past 100 years have brought change affecting in some way every person engaged in agriculture.

Contributions making possible the increase in productivity have come from many sources and not alone, as is often supposed, from the invention, improvement, and use of machinery and power. Major contributions have come through the introduction, adaptation, and improvement of plants and livestock; the increased ability to meet the challenges of insects, pests, and diseases; increase in knowledge relating to the use and replenishment of soils; and improvement in managerial and marketing techniques.

None of these sources has run dry. Few technologies available to agriculture have been utilized fully. Maximum efficiency in farm production has not been reached and is not in sight. It could not be reached without social cost; it cannot be stopped without social cost.

The March of Change

Twenty-five years after the signing of the Declaration of Independence farmers here and abroad were still employing largely the techniques of 3,000 years before. Plows were wooden, crude. In many areas hand tools were favored over plows in preparing soils for seeding. Cotton and corn were planted by dropping seed and covering it with a hoe—much as surburban gardeners of today plant radishes, endive, or sweet corn. Small grains were sown by hand. Cultivation and harvest were performed largely with hand methods.

The cotton gin, invented soon after the Revolutionary War, was one of the earliest of a long series of inventions that changed greatly the character of American farm production. Authorities are not in

[1] This chapter was prepared under the direction of S. H. McCrory, chairman, and Roy F. Hendrickson, secretary, of the committee on technology of the U. S. Department of Agriculture. Mr. McCrory is the Chief of the Bureau of Agricultural Engineering. Mr. Hendrickson is Director of Economic Information of the Bureau of Agricultural Economics. Other members of the committee are: H. T. Herrick, Bureau of Chemistry and Soils; Russell S. Kifer, Bureau of Agricultural Economics; O. V. Wells, Agricultural Adjustment Administration; S. C. Salmon, Bureau of Plant Industry; Earl O. Whittier, Bureau of Dairy Industry; and Paul Howe, Bureau of Animal Industry. The committee was assisted by Roman L. Horne, Caroline B. Sherman, A. B. Genung, and other members of the Department's staff whose contributions are noted in the various sections of the chapter. The introduction and the section on Technology: Its Advance and Implications were written by Mr. Hendrickson.

agreement as to the exact date the grain cradle was introduced. However, there is sufficient available information to fix the date sometime between 1760 and 1800. The iron plow came into general use about 1820 to 1830. The hay rake and the first crude threshing machine came into use soon after. An abundance of land was available for crops and livestock. Export markets opened, especially for grain.

The three decades, 1830 to 1860, constituted an outstanding period in the development of farm machinery. During the Civil War, with manpower on farms reduced and the demand for food increased, there were developed or greatly improved the mowing machine, the steam tractor, the grain separator, and the reaper. The war removed a million men from northern farms alone, while needs for farm products increased—incentives to change quite different from those which now exist.

The stream of mechanical improvements continued to flow. The invention of the internal-combustion engine opened the way to development of the modern tractor. This in turn opened the way to development of more implements. Today farmers can obtain from merchants in nearly every community, or by mail order, a large and growing variety of mechanical aids. Meanwhile, plants have been adapted to meet tests of higher efficiency from the standpoint of increased yields, better quality, and resistance to disease, and to meet a wide variety of growing conditions. Specific qualities in livestock have been stressed in breeding, particularly more efficient feed utilization.

Areas of land that resisted profitable cultivation before have been utilized since the arrival of the tractor. The introduction and adaptation of plants have helped to make this possible. The Corn Belt was moved northward and westward by the corn breeder. The introduction of Russian strains of wheat pushed production westward into dry-farming areas. The development of rust-resistant grains contributed to increasing yields in many wheat-producing areas.

Numerous diseases affecting plants, trees, and animals have been brought under control or weapons have been provided for fighting them effectively. It is said that every trace of hoof-and-mouth disease, which brought heavy losses and costly preventative measures on several occasions, has been stamped out of the United States, even out of research laboratories.

Changes Affecting Rural Living

Technological development has brought and will continue to bring other primary and derivative influences affecting rural conditions of living and not alone in the fields of crop and livestock production. The automobile, the radio, the telephone, the daily and weekly newspaper have increased the means of communication, bringing farmers, in terms of time and distance, closer to each other and to centers of population, education, and entertainment. Motion pictures have affected rural habits and customs. Although they elude adequate measure, their effects on the fashions, speech, and moral attitudes of rural people are many and evident. Rural mail delivery and improved roads have become available to very large numbers of country people. The opening of avenues of communication has meant the breaking down of many provincial barriers.

But like technologies primarily influencing efficiency in production, these streams of influences have not spread out evenly over the countryside. Low incomes appear to be the most important limiting factor in accounting for the large numbers of farm families without telephones, automobiles, radios, electricity, and household labor-saving equipment. Many farms relatively well equipped with modern production tools and techniques are without running water, bathrooms, and electric lights, and other comforts and conveniences. It is frequently said that overemphasis has been placed on production efficiency by farmers generally; that they have passed on their gains too readily as a result of intense competition; and that they have tended to overcapitalize their land, thus limiting their ability to acquire conveniences contributing to raising living standards.

Technology Often Blamed

Technology is often charged with this responsibility. The difficulty is not with technology; it is with the failure of the economic and social system to make needed readjustments.

There are extreme variations in planes of rural living measurable in terms of creature comforts. Wide variations occur in rural housing and the use of household conveniences. Educational opportunities for rural people are unequal in the extreme. Community services vary widely, not alone between regions, but between communities. Resources that form the foundation of livelihood vary widely, of course. These variations point to the necessity of avoiding extremes in generalizing regarding farms and farmers. In considering technology and the farmer, sight should not be lost of the fact that many forces beyond the immediate control of farmers as individuals operate to encourage and discourage utilization of many branches of science and invention.

Although electricity has been very generally used in cities and villages for many years, only about 12 percent of American farms are being served from a central power plant. In Holland 100 percent of the farms are electrified, while in Germany about 90 percent have electricity. It is true that conditions are

not similar here and in those nations; the size of farm units and the character of the agriculture are among the noteworthy differences. Electrification of farms, with public support through creation of the Rural Electrification Administration, is proceeding more rapidly than before. Electrification means the addition of devices and services, many of which contribute directly to increase in productive efficiency of farm workers. The relatively great distance between American farms has been a major handicap to electrification.

Increase in Productivity

In 1787, the year the Constitution was framed, the surplus food produced by 19 farmers went to feed one city person. In recent average years 19 people on farms have produced enough food for 56 nonfarm people, plus 10 living abroad.

Productivity per farm worker increased steadily, and at very nearly the same rate in agriculture as in industry during the 75 years after 1850. Between 1910 and 1930, output per worker increased 39 percent in manufacturing and 41 percent in agriculture.

The Institute of Economics of the Brookings Institution [2] developed an index of labor efficiency in agricultural production, based in part on census reports. Agricultural production per male employed in agriculture during the 5 years centering on 1899 was represented by the figure 100. A decade later the index stood at 99.2, two decades later at 112.1, and during the 5-year period centering on 1929 at 143.1. The index of agricultural production per year of labor for the same periods, it reported as follows: 1897–1901, 100; 1907–11, 97.2; 1917–21, 107.6; 1927–31, 132.9.

The decade of the twenties witnessed a striking increase in farm efficiency in terms of productivity. From 1922 to 1926, production increased 27 percent while crop acreage remained little changed and the number of workers in agriculture decreased.

Studies by the Bureau of Agricultural Economics of estimated amounts of man labor used by growers for producing an acre of 100 bushels of wheat, of 100 bushels of corn, and 500-pound gross-weight bales of

[2] America's Capacity to Produce, 1934, p. 38 (published by the Brookings Institution, Washington, D. C.)

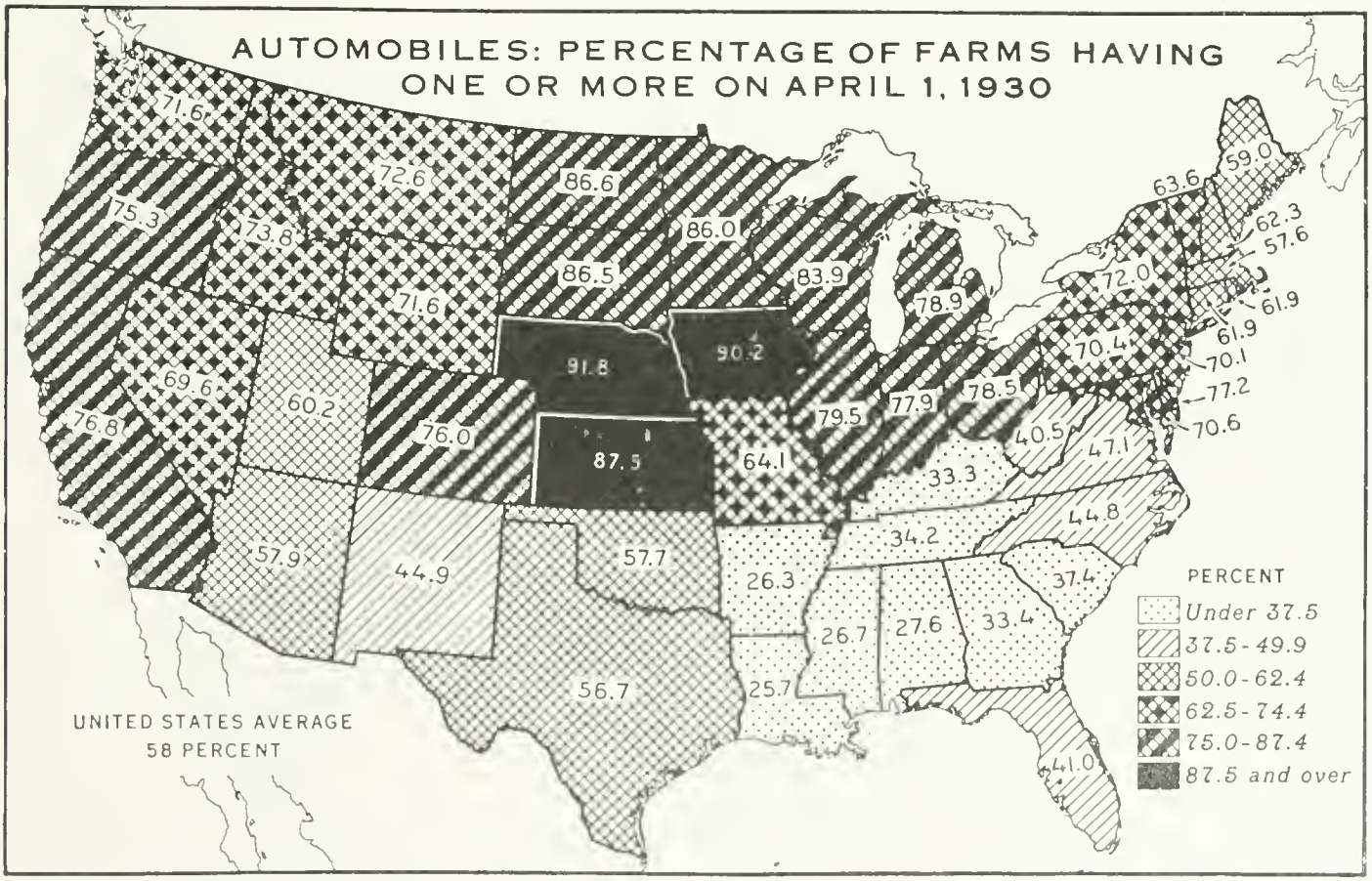

FIGURE 5. As automobiles are kept both for use in farm business and for pleasure, a high percentage of the farms of the country are so equipped. Only in the Southeastern States and in Arizona do the percentages run less than 50, while in the Northern States, from 60 to 85 percent of the farms reported automobiles.

cotton for designated periods (5-year averages) reveal striking changes over a half century (table 10).

Between 1930 and 1935, agricultural production declined more than 10 percent, owing principally to unfavorable weather. Meanwhile, because of urban unemployment conditions, nearly 2,000,000 people were living on farms on January 1, 1935, who were not living on farms 5 years before, and perhaps 2,000,000 farm youth remained on farms who would have migrated to cities if jobs had been available. This had the effect of reducing per capita productivity on farms. Productivity per worker probably declined 20 percent between 1929–30 and 1934–35, with about one-half of this decline due to droughts.

An important factor in increasing per worker productivity, especially during the twenties, was that as mechanical power increased, land formerly required for producing feed for horses and mules was released for the production of commodities offered for sale. The loss of about 9,000,000 horses and mules on farms between 1918 and 1932—and probably a million more in cities—is credited with releasing more than 30,000,000 acres each of crop land and pastures.

In 1920 the production of butterfat per cow in herds owned by members of 452 dairy-herd-improvement associations averaged 247 pounds annually. By 1928 the average had increased to 284 pounds; by 1930 to 302 pounds, and by 1932 to 310 pounds. In the 5 years preceding the depression the number of dairy cows in the Nation was about 5 percent greater than 10 years before. The production of milk was 25 percent greater while it is estimated the consumption of feed did not increase over 15 percent.

Fewer Farms—Fewer Farmers

Farmers do not and cannot apply at equal rates the products of science and invention. Out of this fact arises one of the most significant impacts of technological change in agriculture.

In some types of agriculture per capita productivity has increased much more slowly than in others. The increase in efficiency has been most striking in the production of grain and hay crops. Cotton, fruit, and tobacco production have been given less mechanical assistance than grain and hay. Most cotton and fruit is still picked by hand. Science has aided the

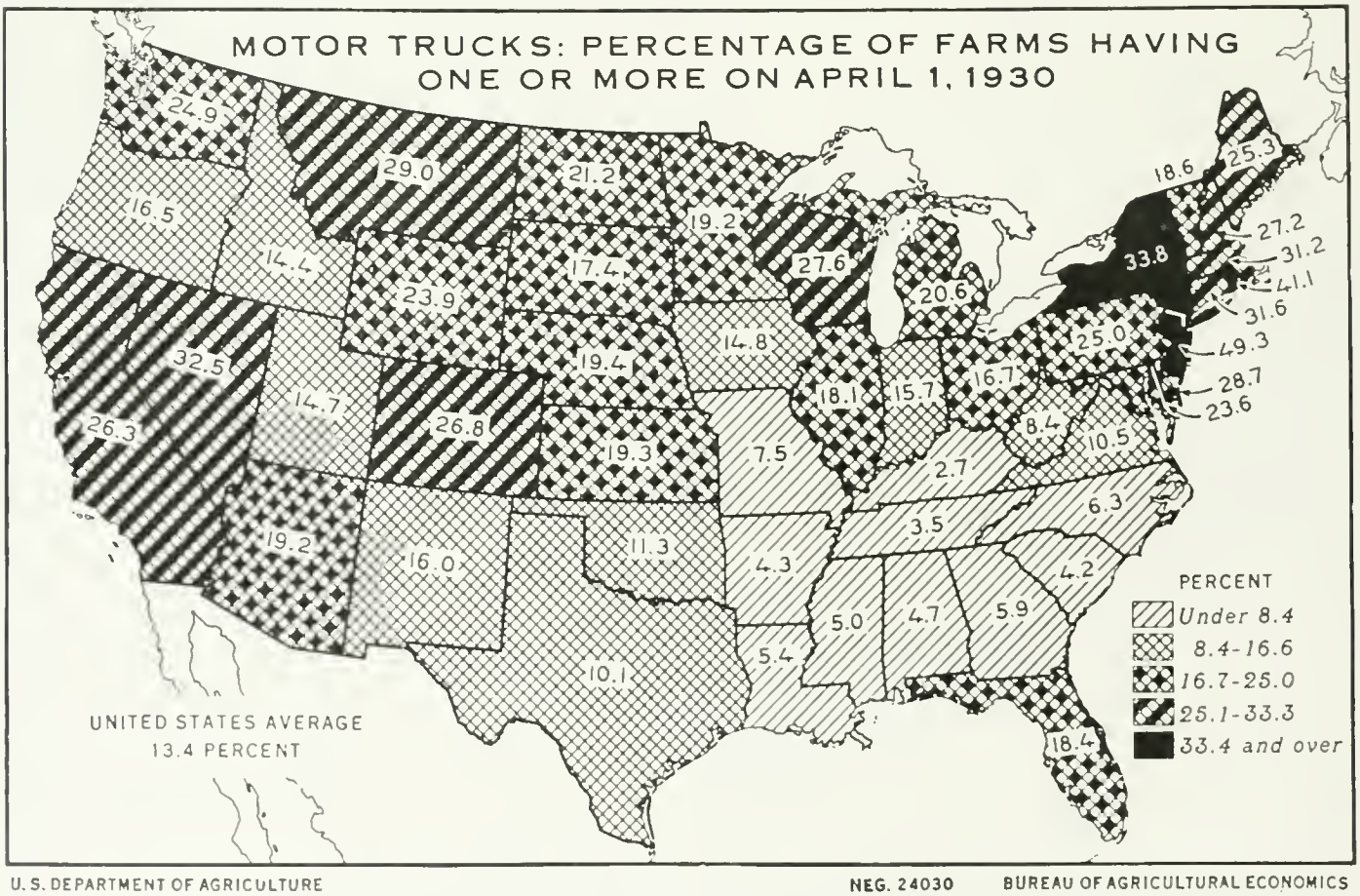

FIGURE 6. The distribution of motor trucks on farms is somewhat less concentrated than is the distribution of tractors on farms. However, probably above 85 percent of all motor trucks are located in the eastern half of the United States, with the heaviest concentration in the general vicinity of New York City. Trucks are more plentiful in the South and West than are tractors.

TABLE 10.—*Estimated amounts of man labor used to produce an acre of 100 bushels of wheat, of 100 bushels of corn, and 500-pound gross weight bales of cotton for designated periods*

	Yearly average for—		
	1878–82	1898–1902	1928–32
Wheat:			
Man labor per acre:			
Prior to harvest, hours	6	5	3
Harvest, do	11	7	4
Total, hours	17	12	7
Acreage harvested, acres	36,160,000	49,929,000	58,722,000
Production, bushels	476,061,000	694,576,000	844,640,000
Yield per acre, do	13.2	13.9	14.4
Man labor per 100 bushels, hours	129	86	49
Corn:			
Man labor per acre:			
Prior to harvest, hours	28	22	14
Harvest, do	18	16	12
Total, hours	46	38	26
Acreage harvested, acres	62,857,000	94,319,000	102,393,000
Production, bushels	1,609,966,000	2,441,882,000	2,557,071,000
Yield per acre, do	25.6	25.9	25.0
Man labor used per 100 bushels, hours	180	147	104
Cotton:			
Man labor per acre:			
Prior to harvest, hours	67	62	48
Harvest, do	52	51	37
Total, hours	119	113	85
Acreage harvested, acres	15,125,000	25,675,000	40,535,000
Production (500-pound gross-weight bales)	5,917,000	10,177,000	14,656,000
Yield per acre (pounds gross lint)	196	198	181
Man labor per bale, hours	304	285	235

production of all of these, particularly in fighting off enemies, such as disease and pests.

For topographical reasons many farms are not suited to effective use of tractors. They may be hilly or poorly drained. A barrier to their use which is far more general is the size of the farming unit or the character of the farming enterprise. Tractors and machines mean a considerable investment. The investment cannot be justified in terms of lower production costs and higher net income if equipment is idle beyond certain time limits. A four-row corn planter is not economically justified on a farm that has only 10 to 20 acres of corn. Thus there has been added to "man-sized farm" and "family-sized farm" the term "tractor-sized farm."

Generally, technological trends in agriculture have been in the direction of larger and larger farm units. Recently in the case of machinery an influence tending to modify this trend has been emphasis on development of smaller units. Many of the smaller units, as in the case of tractors and combines, are high in efficiency relative to larger units.

Many techniques do not require larger farm units and the emphasis on larger units varies a great deal between branches of agriculture and the regions where these are important. Larger-scale operations in some lines, particularly where extensive farming is the most efficient practice, are likely to increase, while at the same time other farms, offering opportunity for intensive land use, may tend to become smaller.

The adjustments toward larger units is not readily made because of limitations on the ability of most farmers to acquire more land and the problem of an alternative opportunity to make a livelihood by those who would sell or lease their farms to others.

Larger units in many types of farming, particularly those which lend themselves to mechanization, tend to reduce production costs and increase net income. They make possible a greater division of labor with more specialization; they justify larger investments in machinery; they make possible purchases of supplies in larger quantities and reduce overhead costs much in the way larger factory units achieve certain economies that are impossible for smaller competitors. But, except for very rare cases incident to the production of specialties, the farm unit, no matter how large, cannot harvest the monopoly gains that in many cases grow out of consolidation of industrial units.

Large units do not escape the fact that the proportion of fixed costs is relatively much higher in agriculture than in industry. Production and prices of farm products are much less certain than production and prices of many, if not most, industrial products. The large farming enterprise is therefore subject to many risks—the vagaries of weather, pests, and diseases, even though technology has erected some effective defenses against these. The farming enterprise built around a family has shown an extraordinary capacity to weather these risks. The family will sacrifice living standards and will continue producing even when returns on its labor are reduced to very low levels.

Potential Farm Production

Thus potential production cannot be dealt with realistically in terms of achieving maximum efficiency quickly. The readjustment, involving as it would widespread reorganization in terms of larger units, could not be accomplished speedily even if that were desirable. The risks involved are of limited attractiveness to capital at the present time. With the existing limitation on alternative opportunities of employment for persons not engaged in agriculture, operating farm owners would not readily part with their holdings.

More persons now are engaged in agriculture than can be supported if a steady rise in rural living standards is to be achieved. Unless there is an increase in

the rate at which rural people are absorbed in industry, the number of persons to be supported by agriculture will continue to increase. Rural birth rates are characteristically higher than are the rates for any other major population group. Rural areas are now responsible for most of the Nation's net increase in population. Some decline in rural birth rates has been indicated in recent years and a trend toward a further decrease is probable, because the gradual spread of birth control is to be expected.

But larger farms and a smaller proportion of the Nation's population engaged in agriculture do not necessitate abandonment of the principle of family-sized farms, a traditional objective in American agriculture. Reorganization of family farms in terms of size and adjustments in practices has been going on steadily in response to technological and other factors for generations. This will continue. Many farms have decreased in size with gains in efficiency when the type of agriculture has changed reflecting some factor such as a new road to a city market or establishment of a canning factory that has made truck growing profitable where more extensive farming was practiced before. There have been and there will continue to be decreases also where there are opportunities for outside employment, often part-time. But where the opportunity for an increased income arises only out of commercial farm production the chief trend will be toward that size unit which promises lower costs—and this promise generally is identified with more land.

Production which is most highly efficient in terms of maximum income for labor and expense involved does not necessarily imply higher average per acre yields. The law of diminishing returns imposes a definite limitation on forcing output. It is a limiting factor which imposes a barrier of practicality to such spectacular feats as producing vast quantities of given products in trays, in greenhouses, or on small areas of land intensively fertilized. The possibility that these methods may prove increasingly practical is, however, by no means closed.

There are many individual estimates that application of maximum use of present available technologies in agriculture might mean an increase from 25 to 50 percent in output, somewhat irregularly distributed among commodities. They cannot be proved, but they

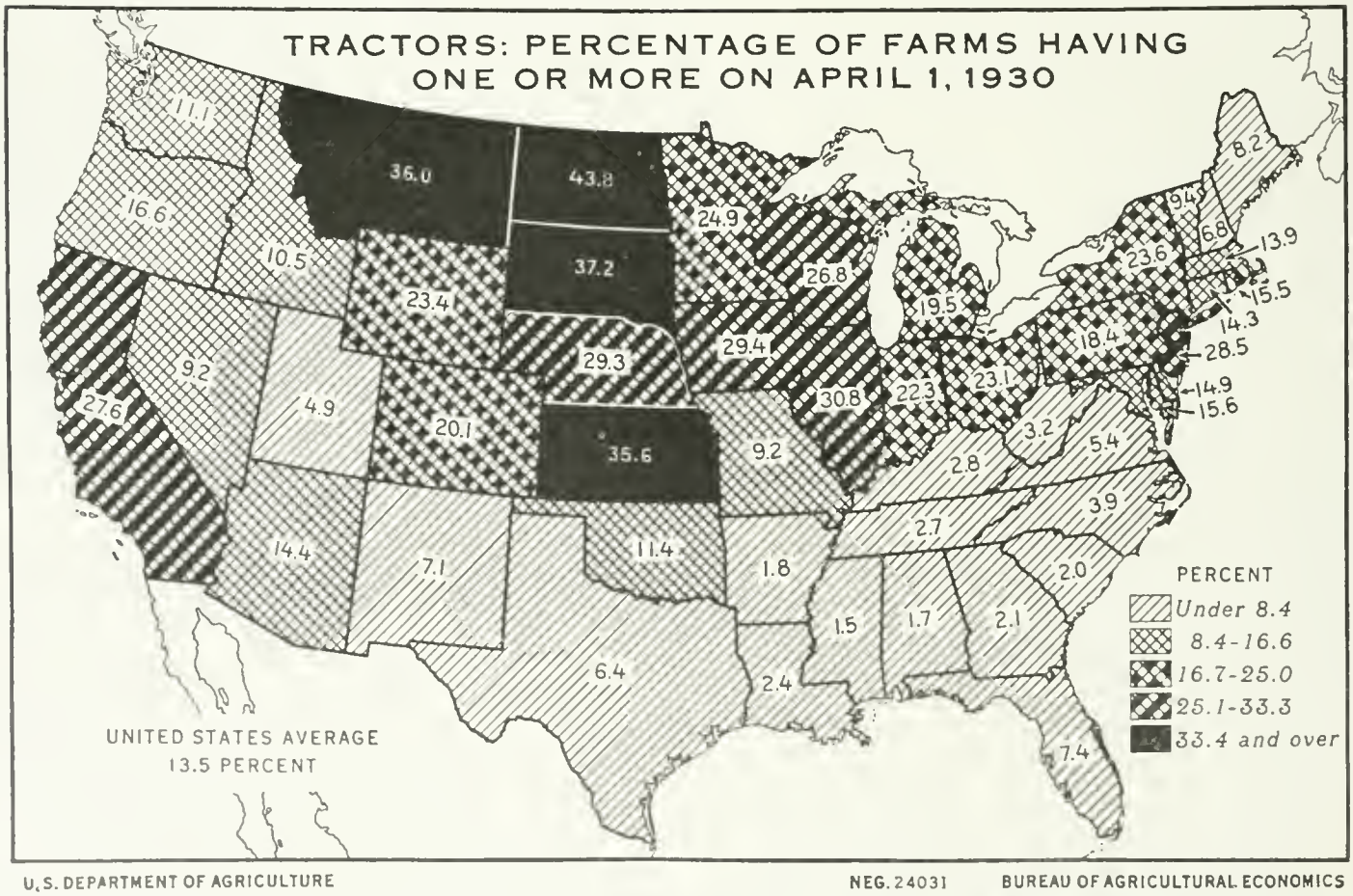

FIGURE 7. If a north-south line were drawn across the Great Plains area dividing the country in half it would be seen that fully 90 percent of all tractors on farms are located in the eastern half of the United States. This concentration, centering around the Great Lakes, is due in part to differences in soil and topography, the greater density of population in the east and the type of agriculture practiced. Note the comparative absence of tractors on farms in the Cotton Belt and in the Western Mountain and range States.

have a sufficient basis of fact to deserve consideration.

Assuming that the present area devoted to agriculture were not reduced, this would mean, over a period of years with average weather, vast unsalable surpluses. For agriculture continues to stand face to face with the problem of an increasing potential capacity to produce out of proportion to its capacity to gain outlets for its products.

Markets for Farm Products

Foreign markets for farm products are not being reopened rapidly. Yet the Nation's farm plant continues to be on a scale capable of sending 12 to 25 percent of its output abroad in years of average crop yields.

Domestic requirements for farm products remain relatively inelastic. There is doubt whether consumption at present levels of consumers incomes would increase more than 10 percent even if it were possible to reduce prices of farm products 25 to 50 percent. Domestic consumption of farm products remained relatively stable during the years 1930 to 1933 while farm prices were extremely low. Since food habits are relatively inflexible, it is doubtful that any but the very poor would consume much more as a result of a substantial increase in consumer income. New industrial uses, while promising, do not at present offer definite outlets for large quantities of products beyond present utilization. This subject is discussed in a separate section later in this chapter.

In principle, gains in efficiency are largely passed on ultimately to consumers. In the case of gains in farm output they appear to be passed on at a rate which is rapid in relation to other industries which are not made up of so many units. In agriculture the factor of many competing units forestalls widespread group action in maintaining price levels.

If all farmers adopted improvements simultaneously, consumers would get most of the benefits quickly under the system of competition that applies to most farming enterprises. But there is a lag in their adoption. As a result farmers who first adopt methods contributing to efficiency gain while the others are following up at an uneven pace. Often these gains are not so great as might be supposed because those who lag are usually the least capable or insistent in defending their living standards.

Social cost would be reduced if the problem of readjusting to a change involving a major gain in efficiency could be solved by farmers, through concerted action. They might reduce their hours of labor or shift production to other lines, unaffected by the new technique, where consumption might be expanded.

Long hours of labor during busy seasons is a farm characteristic. On diversified farms work may be so arranged that the busy season continues around the year with few if any vacations for the farmer or the housewife.

For many other farmers profitable employment during more days of the year is necessary if income is to be increased sufficiently to make higher living standards possible. A promising field exists here for science and invention to create more opportunities of work to fit this need.

As in the case of hours of labor, there are limits to avenues of escape through shifting production. There are many commodities which are not produced in excess in terms of consumer needs, particularly of low-income consumers including many farmers. But farmers cannot produce irrespective of price in terms of exchange value without going bankrupt. Dependent as they are on incomes of consumers, they cannot produce without respect for consumer demand. Thus their interest in consumers of farm products is a reflection of their own place as consumers of industrial and other products. If these were available to them at increasingly lower prices, their concern with maintaining historic price levels for their products would receive less emphasis.

Marketing Techniques

Motortruck transportation of farm products has increased rapidly. It is likely this trend will continue. It has resulted in many changes in the comparative advantages of various producing areas. It is discussed more fully in the chapter on transportation.

Improvements in refrigeration have opened the way to improving the quality of products laid down in consuming centers and in reducing waste. This contribution to more efficiency in agriculture, discussed more fully later in this chapter, is only one of many which may be expected to contribute as much to improving utilization of products as to increasing requirements for them, with variations among commodities. The reduction of waste, whatever its immediate effects may be, can deserve only encouragement in terms of the general welfare.

Perhaps one of the most significant contributions to marketing has been the increase in use of grades and standards. Through these a common language for producers, middlemen, and consumers is being more firmly established. It encourages more emphasis on quality in production: and purchases by consumers on the basis of quality factors. The farmer is also being enabled better to adjust his plans to the markets through improved techniques in market news reporting. The Market News Service of the Bureau of Agricultural Economics distributes quotations on all principal farm products through newspapers, the mail, and radio stations. Farmers who once were unaware of

significant price changes for days and weeks now can hear them over radios within a very short time after they have taken place.

Cooperation in Agriculture

Cooperative marketing and cooperative buying are gaining a place of increasing significance in agriculture. This reflects, to a considerable degree, advances in technology which have made them possible or necessary. It is probable that this trend will continue. It is probable that it will be extremely important in assisting the system of family farms to meet the challenge of new technologies.

Cooperative ownership of farm equipment such as threshers, wood-sawing rigs, sorghum sirup plants, creameries, cheese factories, grain elevators, and terracing machinery may be expanded. Investment in a machine may not be justified for a single farm but the machine may pay its way when used on several farms.

There has been a steady rise in the volume of business done by farmer consumer cooperatives, particularly in the purchase and distribution of production goods such as fertilizers, feeds, twine, gasoline, and oil. This trend is certain to continue.

There has been another relatively new development—cooperative farm-management associations. In these, farmers jointly employ one or more experts to check their operations and to maintain cost and production records. Measures of labor, feed, machinery, and other factors are developed and from these measures are developed programs for changing farm production plans. Individuals and firms are also offering similar services for a fee and many nonresident farm owners have placed their properties in the custody of these specialists.

An important factor in assisting agriculture to narrow the gap between the rise and use of a new technique has been the erection of institutions. The public, through the land grant colleges, the United States and State departments of agriculture, supports scientific research and also the carrying of research results to farmers. There are one or more extension workers in nearly every agricultural county. The task of bringing their research results to farmers and their families has resulted in the development of a vast field of interpretive techniques.

Similarly the field of cooperative management has stimulated the rise of principles and techniques which promise to increase the efficiency of cooperatives as operating entities.

Corporate Organization

Contributions of science and invention to agriculture are most quickly employed by farmers who are possessed of more than average capital. They are better prepared to buy a new machine or buy better livestock or improved seed than their poorer neighbors. Thus, they gain competitive advantages. In turn these farmers already face sterner competition from larger units adequately financed and employing corporate forms of organization. The larger unit, capable of supporting skilled management and specialists may, in some future time, provide farmers now considered wealthy with competition of equal or greater intensity than that now provided by the latter for farmers on undersized farms, on poor land, or handicapped by heavy debts and other burdens. It remains to be seen whether this will become a trend; the extremely large farm unit so far has not proved its capacity to weather the economic shocks to which agriculture has been subjected.

Commercial Farming Stimulated

The rise in technology has stimulated commercialization in agriculture. Numerous functions have left the farms and are now carried on in population centers, functions which once were an integral part of the farm enterprise. In only a few counties, found in the southern Appalachian Mountains, are self-sufficing farms more common than any other type. In 1929 on most of the Nation's farms more than 80 percent of all farm products were "sold or traded", according to the census.

On more than half of the farms, in 1929, commercial production was valued at less than $1,000. On nearly one-half of the farms the aggregate value of products including those used by the family was valued at less than $1,000.

The other half—those with products valued at more than $1,000—accounted for nearly 90 percent of all products sold or traded in that year. The same group produced 58 percent of all products used by farm families. It is probable that this group could, by utilizing some available technologies and with some increase in the area of land for tillage, produce 10 to 11 percent more—thus accounting for all products "sold or traded."

Birth rates are highest among the half who accounted for only 10 to 11 percent of commercial production. This group had lower cash incomes; in general, occupied poorer land, and employed fewer products of science and invention. Their children, by and large, have fewer educational opportunities and more reason to leave their homes and communities to seek employment elsewhere.

Technical progress in agriculture has a significant influence on birth rates. Technology promotes the division of labor and provides incentives to commercialize agriculture. Commercial experience tends to

emphasize economic considerations. A consciousness of economic considerations tends to sensitize parents to the economic responsibilities involved in a large number of dependents. Technologies, by reducing the need for hand labor in many types of farming, have also lowered the position of children as economic assets.

Competitive Tensions Grow

The advance of technology in agriculture has tended to widen the gap in general well-being between farmers who are able to embrace it and those who are unable to utilize many of the fruits of science and invention. This gap is certain to widen. The hoe has not been relegated to the museum. The man with the hoe and the man with a tractor are not competitive equals where they are engaged in the same type of farming.

There is likely to be growth rather than relief in the tension created by the uneven impact of technology affecting large numbers of agricultural people.

Unrestrained competition will lead toward greater concentration of commercial production on fewer farms with an increase in the average size of these farms and fewer commercial farmers. This would mean an increase in the number of farmers with relatively small commercial production, swelling the ranks of self-sufficing farmers. This group will have increasing incentives for migrating to industrial centers and competing there for existing employment opportunities. These opportunities, unless increased as a result of greatly expanded industrial production, are likely to be so limited that migration would be possible for only a relatively small number of those ready and willing to leave rural areas.

With an increase in the number of rural persons hemmed in by limited opportunity in both city and country, opposition to technological advance in agriculture is likely to grow unless a means is devised to relieve tensions.

Concentrations of land ownership and tenancy in commercial farm production are both increasing in the United States. Many legislative proposals have been advanced to check both trends. Proposals to curb the growth of "corporation farming" have been made in several State legislatures. Programs for assisting tenants and sharecroppers to buy land have been offered, notably in the Bankhead-Jones farm tenancy bill before the last Congress.

Alternative Courses of Action

It has been said that the forces of technology cannot be stopped but they can be directed into more socially desirable channels.

If guidance is attempted, "socially desirable goals" will have to be determined. And this determination rests upon decisions as to the character of agriculture that is wanted.

Should agriculture strive for maximum efficiency in production with larger and larger units, more concentrated ownership and management, and fewer and fewer farmers?

Should it seek to support a larger population with small incomes, with an increase in the number of farms—an increase which would limit the application of technology?

Should it seek some middle ground in which the ideal of "family farms" is uppermost, that would limit, without eliminating, further technological advance?

Is there more justification for imposing a bar to technological advance in agriculture than in the case of numerous industries that have moved out of homes and small work shops into large factories?

Instead of seeking to restrain technological advance would social ends be better served by concentrating on efforts to increase industrial production and employment in the expectation that jobs would ultimately be available to many excess agricultural workers?

The answers will be difficult to find and will necessitate reconciliation between many conflicting attitudes. The prospect of more rapid technological advances in coming years emphasizes the need for the early valuation of the social gains and social costs that are likely to arise out of each course.

II. MECHANIZATION AND ENGINEERING[3]

Mechanization of agriculture depends for general utilization upon economic and physical feasibility. It is stimulated sometimes by scarcity of farm labor, at others by relatively high wage scales, or by the uncertainties and economic risks incident to use of transient labor in harvesting crops with high market value.

The expansion of farming into new lands topographically suited to large-scale methods of production accelerated the mechanization of American agriculture. Scarcity of labor caused by the World War influenced introduction of the combine east of the Rockies, after 40 years in use on the western slope. Development of the automotive and other industries in the North Central States reduced the migratory labor available for wheat harvesting to a degree that encouraged introduction of the combine there.

Industrial developments in the Northern and Eastern States and continuation of the movement of the

[3] Contribution from staff of Bureau of Agricultural Engineering, U. S. Department of Agriculture, S. H. McCrory, Chief.

FIGURE 8. The cradle.

FIGURE 9. A hand-rake reaper

FIGURE 10. An early horse-drawn combine.

FIGURE 11. A tractor-operated grain binder.

FIGURE 12. A prairie-type combine with auxiliary motor.

FIGURE 13. A small combine operated by power take-off on tractor.

cotton spinning and textile industries to the Southeastern States caused a marked loss in rural population in the latter area. In Georgia the rural population in 1924 was 22 percent less than that in 1919. Cotton production and acreage declined steadily in the Southeast, but it increased rapidly in Texas and Oklahoma where topography is suited to large-scale production and the climate is favorable to harvesting by snapping and stripping, which has become prevalent in that region in spite of the lower quality of cotton harvested in this manner.

The uncertainty of transient labor was one of the reasons for introducing the combine into the Great Plains. The scarcity and unreliability of transient labor, and the undesirably low standard of the large alien portion of it, have been large factors in promoting the development of machinery for growing sugar beets.

If the United States became engaged in another great war, adoption of a mechanical cotton harvester might be expected. The mechanical picker has reached a stage at which, in the face of labor scarcity, it would prove a very important help in harvesting cotton in the volume necessary for major war needs. Extensive use would provide opportunity for refinement in design and lowering of cost, and for adaptation of cotton varieties to machine harvesting. This would have to be accompanied by further adaptations in ginning and cleaning equipment as have been made for the snapped and stripped cottons in Texas and Oklahoma. Machine-picked cotton is inferior to hand-picked cotton and in view of present wage scales, mechanical harvesting probably does not offer a sufficient saving in costs to offset the lowering in quality.

Many mechanizations, such as for producing grade A whole milk and for washing spray residue from fruit, have been introduced to perform higher quality, more satisfactory services than are practicable, or perhaps possible, by hand methods. The effective control of many insect pests, weeds, and plant diseases depends in large measure upon use of mechanical devices.

Farm Labor Efficiency

The development in farm machinery during the past century has greatly increased the efficiency of farm workers. While the total population of the United States increased from 17,000,000 in 1840 to almost 123,000,000 in 1930, the persons engaged in agriculture increased only from 3,720,000 to 10,480,000. In 1840, agricultural workers[4] comprised 77.5 percent of all persons gainfully employed in the United States; since then, the proportion has dropped steadily until in 1930 it was only 21.5 percent.

[4] All persons 10 years old and over, reported by the census as gainfully employed, engaged in agriculture.

That the income of the agricultural worker tends strongly to increase with increase in power and machinery available for his use is indicated in comparing by States the average gross annual income, available power, and value of farm mechanical equipment. Alabama has the lowest gross income per worker, $492 including the value of his products consumed by his own household, with 1.5 horsepower available and $142 invested in machinery; Nevada shows the highest income, $2,263, with 9.5 horsepower and $739 investment. Montana shows the greatest horsepower per worker, 22.5, with $953 invested in machinery, and a gross income of $1,798. North Dakota has the highest investment per worker, $1,119, with 18.0 horsepower and $1,806 income. Fragmentary data from foreign countries seem to indicate that throughout the world increase in amount of power available, within the limits observed, tends to increase the income of the agricultural worker.

Rural Electrification

Agriculture, although a large user of mechanical power, has thus far made relatively little use of electrical power as compared with other industries. In December 1935 less than 789,000, or 11.6 percent of American farmers, had electric power available other than individual lighting plants. The average consumption of central-station power per farm varied in 1935 from 558 kilowatt-hours in West Virginia to 11,799 kilowatt-hours in California.

On certain types of farms electricity can be used in many ways to lower the cost of production or improve the quality of products. On dairy farms it can be used for milking, separating, cooling, pasteurizing, sterilization of utensils, and refrigeration of products. On poultry farms it is used for heating incubators and brooders, for illuminating laying houses to increase egg production, and for mixing feed. In market gardening this power is used in pumping water for irrigation and for washing vegetables, in heating hotbeds, and refrigeration for temporary storage of perishables. On grain and livestock farms fewer jobs have been found for electric power, but it can be used for pumping water and for storing grain and hay. Where water is pumped from wells for irrigation of field crops, electric power is used extensively. More than 200 different uses of electricity on farms have been noted. Rural electrification has its most immediate effect in the home.

Experience in other industries indicates that only a beginning has been made in adapting farm operations to economical use of electricity. Further research will make it practicable to increase greatly the farm electric load so that this power will be very profitable to the user. Ultimately, there will be a considerable in-

crease in the use of automatic and semiautomatic machinery for such purposes as pumping water and operating processing machinery; an extensive use of heating devices for hotbeds and stock-watering tanks; perhaps, air conditioning; and, possibly, substitution of electric for other power in field operations. Rapid extension of power lines to serve farms, which has been started under public auspices, will do much to stimulate progress and will make possible introduction of many labor-saving devices in farm homes. The wise use of electricity in agriculture should lower cost of production, improve quality of produce, lighten the labor of farm people, and make possible more comfortable living on the farm.

Refrigeration

The application of refrigeration to farm products has done much to insure that perishable farm products such as meat, milk, fruit, and vegetables reach the consumer in good condition, and has made possible many improvements in diets. Refrigerator cars and refrigerated trucks provide even the smallest and most remote towns with dependable supplies of fresh meats. Fruits and vegetables can be shipped across the continent and reach the consumer in perfect condition. Refrigeration in transportation has permitted shift of the production of perishables away from the localities of consumption to the regions best suited for growing them.

Household refrigerators have been greatly improved through mechanical operation until they can safely store perishables for considerable periods. Extension of electric power in rural areas will make this facility possible in many homes not now satisfactorily equipped. Gas or kerosene refrigerators can be used where electric power is not available. Experiments with community storage houses in which units of different sizes have been held at agreed temperatures have given indication that such storages would fill a need and be profitable in many communities, particularly in warm climates.

Research is needed to develop small, low-cost refrigerated storages for farmers and small cooperatives, and to work out improved methods of storing perishable products on the farm, so that surpluses of certain commodities can be held longer and a better distribution be obtained.

Farm Buildings

Changes in building types take place slowly because of the long life of well-built structures. In New England, for instance, the majority of farm dwellings were built more than 50 years ago and a great many more than 100 years ago.

In recent years farm buildings have depreciated greatly in value both through deterioration in physical value, partly the result of depressed farm incomes, and through obsolescence. The farm housing survey of 1934 showed about half of the farmhouses needed major repairs or replacement, with the other buildings in about the same condition. Changes in farming methods and in farm production have modified the requirements for buildings, and adoption of automotive machinery in place of animal power, on the farm and in the city, has reduced the shelter and feed storage needed for work stock.

A program of readjustment is needed that will take advantage of new or improved methods in farm-building design and construction and of researches in farmstead planning. Studies have developed arrangements more economical of labor in caring for livestock, and including accommodations for such equipment as feed grinders and litter carriers. The balloon type of barn framing has been developed as more economical than the heavy frames of early days. Concrete foundations and floors instead of the old log foundations and the pole and plank floors, and concrete walks, feeding floors, dipping vats, and other structures have permitted better sanitary conditions and thus contributed largely to more healthful milk supplies for city as well as for country people. Construction methods providing greater safety against fire and storm, and better protection against weather, have been developed.

Use of insulating material on farms is comparatively new but is rapidly being accepted. A better understanding of ventilation, moisture control, air conditioning, and lighting requirements may be expected to bring about changes in building design that will provide greater comfort for man and beast and improved quality in stored products.

Much progress has been made since the day of the pioneer whose large family was housed in a log cabin lighted by candles, heated by open fireplaces which also served for cooking, and supplied with water from the old oaken bucket. Yet the farm housing survey showed that only about 15 percent of the farms have the safety and convenience of electricity; 27 percent have kitchen sinks and drains; 17 percent have cold water piped into the house; 8 percent have piped hot water; 9 percent have flush toilets; 8 percent have furnace heat; and 4 percent have gas or electricity for cooking.

Reclamation of Wet and of Arid Lands

Drainage.—Technology has developed the equipment and methods for building the drains which have con-

verted more than 50 million acres of swampland into farms. Studies of run-off and of hydraulics have determined the drainage requirements of such areas and the fundamentals of designing the drainage works. The 1930 Census reported more than 84 million acres in organized drainage enterprises. The States of Ohio, Indiana, Illinois, and Iowa rank high both in extent of drainage improvements constructed and in agricultural development. Where community drainage enterprises are operating, farm lands as a rule are highly developed.

The drainage work thus far undertaken has reclaimed those lands most easily occupied. There are yet in the United States some 60 million acres of varying degrees of fertility that when needed can be made available for agriculture by drainage. But the cost of doing this will be much higher than that for the land already drained because of unfavorable location, heavy timber cover, or other disability. In their present condition these lands are valuable for grazing livestock, sheltering wild life, or growing timber. When increasing markets, deterioration of hill lands, or other conditions make it desirable, these areas can be drained and brought into cultivation.

Underdrainage has been profitable to farmers, but in the past decade little of such work has been done because of low farm incomes and the extended period of scanty precipitation. There are indications that with return of normal conditions use of underdrains will greatly increase, and that they will become common in many sections where now comparatively unknown.

Irrigation.—Only through application of developments in construction machinery and materials has it been possible to bring water to a large part of the 19,500,000 acres irrigated in the United States in 1930, upon which is so largely based the agriculture of a great portion of the West. The huge dams, canals, tunnels, flumes, and siphons could have been neither built nor designed without engineering technique, and expansion of the productive acreage sufficiently to pay the cost has required further technology.

The supply of water available for irrigation in some sections has been fully utilized, although with complete economy in very few localities. Studies of water requirements of crops and of methods of applying the water are gradually bringing about correction of wasteful use. While irrigation is as old as the Pyramids, only recently have devices been perfected for accurate measurement of flowing water. This achievement has made possible detailed studies of the use of water by crops, losses of water in transit, and waste of water from fields and from canals. It has resulted also in more equitable apportionment of limited water supplies to users, thus eliminating one of the chief causes of friction in irrigated areas.

Areas that can be irrigated cheaply by direct diversion of water from streams have been almost completely occupied. Any large areas yet to be brought under irrigation must be supplied with pumped or stored water. Creation of storages for this usually must be coupled with development of power if the cost of obtaining water is not to be greater than the value of the crops that can be grown with it. Nevertheless, indications are that for several decades the area irrigated will continue to increase, until the practically available water supply is wholly utilized.

Far more effective utilization of waters available for irrigation than has been possible heretofore is being promoted by the making of snow surveys high in the mountains from which streams flow, in the arid region. Irrigation water-supply forecasts based upon measurements of the water in the snow cover enable the farmers to plan their cropping programs so as to get the greatest return from the water that will be available, and permit economical regulation of releases from reservoirs.

Pumping from wells to supplement other water supplies will increase in importance in many of the older, highly developed sections. Expansion of the area so irrigated is encouraged by improvements in pumping equipment, extension of electric power lines, and cheapening of fuel costs. In many areas the drafts upon the underground waters are seriously depleting that supply. Studies of means to increase natural recharge by spreading floodwaters upon porous tracts have met with sufficient success in southern California to encourage ambitious attempts of the same kind in other sections of the West.

Irrigation agriculture, within the available water supply, escapes the greatest hazard of farming in a large part of the United States. Federal irrigation promotion was undertaken primarily to make public lands usable and to foster development of sparsely settled western States. The excessive drought of 1934 stimulated migration from the semiarid region to localities where irrigation is the regular practice. Settlement upon unoccupied fertile lands in irrigation enterprises seems to offer aid in the relocation of people from drought-stricken and wind-eroded areas, and would promote the prosperity of communities that lack farmers to utilize the irrigation facilities available.

In the humid States there probably will be some extension of irrigation for truck crops, fruit crops, and citrus, and probably for other high-priced crops such as hybrid seed corn and nursery stocks.

III. PLANT BREEDING AND IMPROVEMENT[5]

Plant breeding and improvement is technology of a character which has had and will continue to have a significant bearing on processes affecting all agriculture. Research covers many fields, including plant production, plant utilization, and sciences related to them. The range of activities covers practically all plants, wild and cultivated, for which man has found a use as food, clothing and fiber, drugs and medicines for man, or poisons and repellents for insects and diseases.

Improvement in Varieties of Spring Wheat

During the last 30 years extensive efforts have been made to evolve improved varieties of wheat for the northern Great Plains. In 1919 a stem-rust resistant variety was distributed to farmers, but proved unsatisfactory because of weak straw and susceptibility to leaf rust, loose smut, and bunt. It served a useful purpose, however, as one parent of Ceres, a variety distributed in 1926 which has shown great resistance to both rust and drought. In 1935 approximately 5,000,000 acres were grown. Ceres, and Marquis, which was introduced from Canada in 1912 and 1913, are now responsible for an estimated annual increase of 50 to 55 million bushels over the crop that might have been produced on the same acreage with the varieties available 25 to 30 years ago. A new variety, Thatcher—distributed in 1934—is expected further to reduce losses from stem rust in western Minnesota and the eastern Dakotas.

Varieties of Wheat Resistant to Bunt

Bunt, or stinking smut, takes an annual toll of millions of dollars from wheat farmers all over the country. In recent years this disease has been increasing. This disease can be controlled by seed treatment, except in the Pacific Northwest where the organism that causes the disease lives over in the soil. The only remedy there, it seems, is to develop resistant varieties of wheat.

The breeding of such varieties in the past has been complicated by the fact that there are several races of bunt. A particular variety of wheat might resist one or more races of bunt but succumb to others. In recent years a number of varieties of wheat that are resistant to a considerable number of races of bunt have been discovered or produced by scientific breeding. The result may be a material reduction in one of the hazards of wheat growing, with a consequent increase in the security of the farmer and a decrease in his costs of production.

[5] This section was prepared under the direction of S. C. Salmon, Bureau of Plant Industry, U. S. Department of Agriculture

Hybrid Corn

Extensive field-plot tests in the Corn Belt indicate beyond reasonable doubt that materially better yields can be expected from the use of hybrid seed than is otherwise possible. This increase for the better hybrids is as much as 20 percent for a considerable part of the area under consideration. The plants of most of these hybrids remain erect decidedly better than ordinary corn, a factor of great importance where mechanical pickers are used. Also some of them are more resistant to diseases and insects of various kinds, including the chinch bug, European corn borer, and the corn ear worm.

On the other hand, no satisfactory hybrids have as yet been produced for certain portions of the Corn Belt, particularly the southern fringe. On poor soils and in areas of deficient rainfall where yields are uncertain, the use of hybrid seed may not justify the extra expense. Where corn has come to be the main source of income, however, the extra expense and trouble involved in production of hybrid seed is meeting little resistance. When hybrid corn comes to be widely used, the average farmer probably will buy seed each year rather than try to produce his own.

In recent years the supply of hybrid seed has about doubled each season. Even so, the demand in the Corn Belt has far exceeded the supply. At the present rate of increase there will be 12 to 15 million acres of hybrid corn in 1940 yielding, it is estimated, an average of 35 bushels an acre, or an increase of about 15 percent over present yields. If this development leads to a reduction in acreage, as is thought probable, farm labor in the Corn Belt will undoubtedly be affected.

The Rice Industry in California

Rice growing in the Sacramento and San Joaquin Valleys of California is an example of a new industry developed largely as a result of experimentation. Prior to the inception of research work at Biggs, California, in 1912, no rice of consequence was grown in these valleys. At present, above 125,000 acres are annually devoted to this crop. With average yields of 50 to 60 bushels an acre, the yearly output is now valued at 6 to 7 million dollars.

The Weed Fallow for Tobacco

It is a unique outcome when an apparently careless and slipshod method of growing a crop turns out to be the most profitable. This is about what has happened in tobacco growing. It has been known for many years that under a system of farming in which tobacco is grown in rotation with other crops, better returns are obtained, with certain exceptions, than

from an equal acreage planted to tobacco year after year. It is also well known that some rotations are better than others. Recently, however, it has been shown that a weed fallow, that is, land that has been permitted to lie fallow with no cultivation whatever and with such weeds as will naturally grow, produces a better return per acre than can be produced by the best rotation with a cultivated crop. The yield is better than might be expected, but the principal gain lies in the superior quality of the tobacco. The increase in the value of the crop may be as much as $200 or $250 an acre.

Curly Top Disease of Sugar Beets

West of the Rocky Mountains the sugar beet is subject to a disease known as curly top. It is a virus disease, known since 1897 and transmitted by the beet leafhopper which breeds on weed plants of the desert lands adjoining beet-producing areas. When the weeds dry up in the spring the leafhoppers migrate to the beets. Half or more of the plants may be infected by midseason, and by late summer or early autumn the infection has occasionally spread to the entire crop. During the last two decades the disease has become so serious that it is now recognized as the chief limiting factor to sugar-beet production west of the Rocky Mountains. In 1926 and again in 1929 losses to growers were estimated at from $10,000,000 to $15,000,000.

In 1929, Congress, taking special notice of this threat to a large farming area, made an appropriation for special study. As a result, varieties of sugar beets resistant to curly top have been produced and a beet-seed industry has been developed in the United States. Until recently commercial beet growers in this country had to import their seed from Europe. By careful selection and breeding, resistant varieties have now been developed; a new industry for the United States, the production of sugar-beet seed, is now firmly established.

Improving the Quality of Cotton

About 25 years ago the Bureau of Plant Industry of the United States Department of Agriculture undertook an extensive research program designed to improve the quality of the American cotton crop. Several factors, up to that time, had contributed to its progressive decline. In concentrating on early maturing varieties—in order to escape the ravages of the boll weevil—cotton growers had rather consistently sacrificed quality of fiber. In many communities several varieties of cotton were planted in adjacent fields, resulting in cross-pollination and mongrelizing of good and bad varieties. Moreover, the gradual depletion of soil resources tended to encourage a general decline in quality. For more than 20 years experiments have been carried forward, resulting in superior varieties of early maturing cotton where early maturity is a highly desirable quality.

Along with these improvements from the point of view of quality has gone the development of the single-variety community plan for keeping the varieties pure and producing cotton of superior quality in large even running lots readily available to manufacturers and foreign markets.

Mosaic-Resistant Sugarcane

The history of sugarcane production in the southern United States illustrates in a striking way what can happen to any crop that is grown intensively. About 1908 there began a more or less gradual decline in acreage planted to sugarcane, and a reduction in total output as well as in the output per acre. The principal features of the decline are illustrated in figure 1. Large areas of the best alluvial lands of the Mississippi delta, to say nothing of other less productive areas, remained idle and grew up in weeds. Many factories there were closed and many of the small farms and large plantations were foreclosed.

Several factors contributed to the disastrous decline in production and yields such as, for example, occasional plant diseases. Root rots and red rot had long been recognized as important yield-limiting factors, but the disease situation was not regarded as particularly serious until the discovery of a mosaic disease in 1919. This was soon shown to be a virus disease and to be transmitted from diseased to healthy plants by the corn aphid. Numerous grasses occurring as weeds in sugarcane fields served not only as hosts for the aphids, but were also susceptible to the disease. Moreover, it was shown that the aphids were carried long distances by the wind. From these facts it seemed evident that control could not be effected through the means of seed-cane selection and roguing.

Continued investigation revealed considerable variation in the severity of the disease in susceptible varieties, and a few were found to be immune. One of the latter, known as Cayana, though unsuited for sugar production, found immediate utilization in Georgia, Florida, Alabama, and Mississippi for sirup production.

Many varieties of sugarcane were imported from foreign countries and tested by the Department of Agriculture. Some possessed sufficient tolerance to mosaic and other diseases to justify their use in Louisiana and were distributed in 1924 and 1925. As a result of these introductions the average yield for the Louisiana crop increased from the low figure of 6.8 tons per acre in 1926 to 16.2 tons in 1938, and 18.8 tons in 1929. Still other improved varieties, including

four bred by the Department, were distributed during the period 1930 to 1935.

As indicated in figure 14, the industry seems definitely on the way to recovery.

Recent Advances in Horticulture

As a result of crossing two varieties of tomatoes in 1917, a selection was made which was introduced about 1925 under the name Marglobe. This variety, because of its high resistance to Fusarium wilt and to nailhead rust, has done much to save the tomato industry of Florida and other winter-garden areas.

Cabbage yellows is a serious disease which affects the cabbage crop from Long Island to Colorado. The disease is caused by a fungus that persists in the soil. In 1910 two cabbage plants were selected that had survived the yellows disease on a badly infested field.

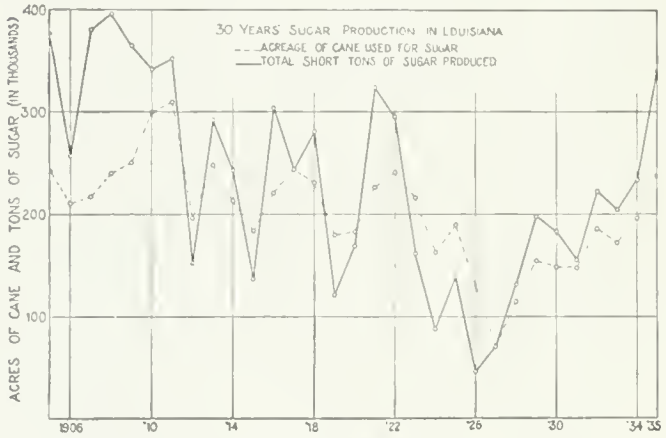

FIGURE 14. Because of the combined damage from mosaic, red rot, and root diseases of the cane, the Louisiana sugar industry suffered a long period of declining yields culminating in virtual bankruptcy in 1926 and 1927. Introduction of resistant varieties has restored the industry, and promises stabilization of production on higher per acre levels following application of the results of further research by the department and cooperating State agencies.

From these, a variety of cabbage strongly resistant to this particular disease has been developed over the years.

Lettuce is subject to two diseases known as brown blight and lettuce mildew. Through scientific breeding, highly resistant varieties have been developed, resulting in a saving of many millions of dollars to the farmers in the Southwest.

And so with other plants. Resistant varieties are constantly being sought out and cultivated with great care, and at the same time a relentless war is being waged against disease and pests.

Soybeans in the Corn Belt

Only about 5,000,000 bushels of soybeans were produced in the United States in 1925 while 10 years later production was in excess of 39,000,000 bushels—a good example of what can happen as a result of constant research and improvement.

The crop was introduced into this country more than 125 years ago, but was never considered more than a forage or feed crop until after the World War. The development of new varieties suited for growing in particular areas, and for particular purposes, has been an outstanding feature of the rapid increase in the crop. Recognition of the value of the crop in dry seasons, immunity to chinch-bug injury, and the increased demand for the crop for industrial and food purposes have been important contributing factors.

Until recently the industrial outlet for soybeans was limited. But in the last few years new uses have been found, as in the manufacture of paints, enamels, varnishes, lard and butter substitutes, linoleum, oilcloth, insecticides, lecithin, disinfectants, core oil, soap, printers ink, medicinal oil, and waterproof goods. Production of soybeans is now a stable and important industry.

IV. TRENDS IN ANIMAL TECHNOLOGY[6]

Our domestic farm animals represent millions of highly adaptable factories for the conversion of raw materials into food, fiber, or power. Both as factories and as storehouses they tend to stabilize the land's production through the seasons and through years of highly fluctuating production.

The purpose of Federal, State, and nongovernmental forces engaged in animal technology efforts is to aid, through research, professional advice or law enforcement, in the fulfillment of livestock's greatest usefulness. It is a constantly changing field in which man's increasing fund of knowledge widens the possibilities, presents new theories and problems for solution, and renders the future difficult of prediction.

The trend is toward greater adaptability of livestock to trying environmental conditions and to man's needs, better utilization of feeds, increased vigilance and skill in prevention of parasite and disease losses, and marked progress toward eradication of the most serious infections from our herds and flocks. The result should be to open new areas to livestock production, to increase the chances for success with livestock in all areas, and to contribute directly and indirectly to human health.

On the other hand many advances in technology in all producing units of the livestock industry seem to be favorable to a trend toward concentration of produc-

[6] This section was prepared by Paul E. Howe, Principal Chemist, and William Jackson, Associate Animal Husbandman, Bureau of Animal Industry, U. S. Department of Agriculture.

tion and commercialization. Strains of animals bred for high efficiency require intelligence, appreciation, and care in their use as breeding stock if their use is to be profitable, for they cost more to produce than inferior or unproved stock. Carefully planned rations must be fed to make the greatest use of the animals' inheritance. The greater drain on the animals' constitutions resulting from high production calls for double precaution in feeding and management or the result may be greater susceptibility to disease.

The producer who can succeed in breeding efficiency into his flock or herd will have a tremendous advantage over the one who does not. Registered Shorthorn steers in controlled experiments have required as few as 373 days and as many as 566 days to reach a live weight of 900 pounds—a difference of more than 50 percent. Similar differences have been found among swine and probably exist among sheep. The average hen in flocks of this country produces only about 80 eggs a year according to census estimates, while superior flocks of progeny-tested birds produce more than 200 eggs a year. Neither geneticists nor practical breeders have found a way to reproduce efficiency without fail, but the possibilities in that direction are increasing, as shown by many encouraging results, particularly with poultry, dairy cattle, and swine.

The production and proving of superior germ plasm in farm animals is expensive, and will probably continue to be for decades to come. This also tends to concentrate superior stock and to encourage larger production units under highly skilled management. But a number of eventualities may result in discouraging concentration of production, and aid the smaller producer.

One of these is the development of breeding farms from which will be distributed superior germ plasm, possibly by mail, in capsules. However, such a possibility will, in itself, mean a highly specialized concentration of superior breeding stock on a few farms producing such germ plasm. It is also possible that the larger producers will make most of such a development.

Another effect toward decentralization of production is to be found in breeding studies to develop types of animals suited to regions of harsh environment, and in nutrition studies to find correctives for mineral and vitamin deficiencies of the pasturage, crops, or water of deficient regions. An example of the first is the work being done by both public and private experimenters in crossing the Guzerat and Africander breeds of cattle with our beef breeds of British origin to develop strains of cattle better adapted than we now have to trying conditions of heat, sparse vegetation, and insect and parasite menace in the South and Southwest. Examples of the second are studies of rations that will compensate for iron deficiency in grazing areas in Florida; phosphorus deficiency in the coastal plains region and the Southwest; iodine deficiency in the goiter regions of the Northwest; and studies of protein, mineral, and vitamin content of forage and harvested crops at various stages of immaturity and under advanced methods of preservation and handling.

A third trend seemingly inimical to great concentration is found in the greater possibilities of infection when animals are crowded. Both concentration and unlimited forcing of domestic animals and poultry for higher efficiency make it difficult to maintain vigor in breeding herds and flocks. Despite improvements in feeding and sanitation practice with swine during the last two decades, the best available information shows that there has been but little change in the average number of pigs weaned per litter. Advances by progressive farmers have apparently been counterbalanced by recessions among careless farmers.

A study of a group of Illinois farms where the McLean County system of swine sanitation was followed showed 5.8 pigs weaned per litter as compared with 5.4 pigs per litter on farms practicing no especial precautions. There was also a saving of feed amounting to 1½ bushels of corn per pig fed to market weight in favor of practicing sanitation. There is evidence that the McLean County system or some modification of it, and the greater use of pasturage have been adopted by swine growers in many sections of the country. In general, pigs raised under the sanitation system develop more rapidly and have a greater market value at a given age. And when the system is followed closely, as many pigs can be weaned and raised from two sows as from three under ordinary methods of swine management.

Although parasites of livestock are widespread in practically all sections, economic loss from them is intensified in the South for such reasons as a favorable climate, an abundance of moisture, and the presence of insect intermediate hosts favorable to their multiplication and spread. In the ordinary run of hogs raised in the South, kidney-worm infestation is widespread.

From 85 to 90 percent of the livers and about 90 percent of the kidneys are infested. Such worms reduce the host animal to a state of unthriftiness characterized by stunted growth, appearance of malnutrition, and a predisposition to disease because of lowered vitality. Research has developed a method of kidney-worm control whereby these losses can be sharply curtailed and can be eliminated eventually if the control measures are followed explicitly.

Nation-wide efforts to eliminate altogether the presence of some of the worst livestock scourges are meeting with gratifying success. Ninety-one percent of

the original cattle-tick quarantined area of over 700,000 square miles has been freed of ticks and released from quarantine in the 29 years since the campaign of eradication began, and the infested areas have been reduced to a total of 62 counties and 6 parts of counties in 3 States from the beginning of 985 infested counties in 15 States.

The degree of infection of tuberculosis among cattle has been reduced from approximately 4 percent in 1922 to less than one-half of 1 percent, with all the counties of 40 States now in the modified-accredited area. The fight against Bang's disease, or infectious abortion, is just getting well under way in this country, with about 700,000 head of cattle being tested each month, on a voluntary basis, and an indicated infection for the entire country of from 13 to 15 percent.

A number of diseases and parasites of animals such as anthrax and certain species of hookworms are direct menaces to human health. Beef and pork tapeworms are acquired by humans as a result of eating raw or improperly cooked beef and pork, respectively. Creeping eruption, a painful and troublesome skin disease of man in certain parts of the South, is due to the invasion of the human skin by larvae of species of hookworm parasitic in dogs and cats. Control measures developed in recent years have helped to cut down such incidence of infestation of man. Quarantine measures, at our ports of entry from foreign countries, and inspections at public stockyards, are aiding in the prevention of outbreaks that can be of serious social consequence.

Man's constant effort to increase the output of his animals, and particularly the tendency in some branches of the industry to concentrate in large production units, is bringing new problems in disease and parasite prevention and control. For example we have the "poultry factory", with thousands of breeding, hatching, brooding, laying, and fattening units in close confinement under one roof. As an outgrowth of the development of artificial incubation and brooding which began about 30 years ago, fully 700 million, or nearly half of the chicks hatched annually, today are produced by commercial hatcheries. An increasing percentage of these are being raised in multistoried houses or similar close confinement, without access to sunlight or free range; in air-conditioned rooms kept at even temperature, and lighted by red bulbs, for chicks, to prevent cannibalism; with vitamin, mineral, and protein supplements provided to offset the absence of sunlight and diet deficiencies due to confinement; and with segregation of adult birds from one another and from the droppings, and periodic sterilization of the cages with live steam to avoid losses from diseases or parasites.

A new development is the possibility of determining the sex of chicks when hatched, permitting a further specialization. About 70 percent of the Leghorn chicks hatched this year on the Pacific Coast were sexed, and a considerable percentage of the cockerels killed at once. The man who is in the poultry business for egg production only can now purchase day-old pullet chicks, enabling him twice the number of pullets with the same expenditure of feed and labor, and with the same equipment. The sexing of day-old chicks in the Middle West is already acting to stimulate commercial broiler production, which will likely in turn affect the production of roasting chickens.

A study of data from all parts of the United States shows a tendency for pullets and hens that are being forced for egg production to be much more susceptible to disease. Records from 1928 to 1933 on 126 farms in San Bernardino County, Calif., averaging 956 hens per farm, show an uninterrupted increase in laying-hen mortality from 19.49 per cent in 1928 to 38.9 percent in 1933. Records of mortality among pullets and hens in egg-laying contests show an increase of from 11.5 to 16.3 percent in 7 years in Connecticut; of from 13.2 percent in 1921–25 to 55.5 percent in 1929–32 in Ohio; of from 14.0 to 26.6 percent in 9 years in Georgia; and from 6.58 to 24.77 percent in 14 years in New Jersey.

Studies of the causes of these losses show that disease is the most important, and that diseases of the egg-laying function of the bird are the most prevalent of all diseases. The underlying causes are greater opportunity for spread of infection when animals are concentrated in small space and failure of advances in technology to compensate for the forcing for production under conditions of unnatural environment. Both of these causes seem correctable. The uncertain quantities are man's ability to make full use of his own technological advancement, and his willingness to do so. There is a point beyond which precautions cost more than they are worth; and men are careless.

Much progress in animal product technology has taken place. New uses have been found for animal products and valuable guides have been developed to improve production practice. A recently invented device for determining wool fineness and cross-sectional variability has been found useful also in the cotton, silk, and rayon industries. It promises to do much toward coordinating the aims of the producers of fibers with the needs of the manufacturers and the users of the finished fabrics. Human medicine has developed some amazing uses for animal glands and gland extracts: the pancreas to supply insulin for treating diabetes, the adrenals to supply cortin for treating Addison's disease, the parathyroid to supply parathormone for treating abnormal calcium metabolism,

the anterior pituitary or its extract for treating various sexual disorders and use in gynecology. Meats and meat-food products have been cured, processed, and merchandised in a great variety of more useful and more attractive ways, and recently the widespread extension of the use of subfreezing temperatures for the storage of fresh meats promises a new means of storing surpluses for times of scarcity, and of the use of fresh meats in all parts of the country at all times of the year.

Summing up, it is probably fair to say that the time is decades distant when technology will give man a sure command of the production of livestock for specialized purpose and to fit specialized agricultural conditions, such as he enjoys with many plant crops and with mechanical inventions. Animal germ plasm and behavior are less amenable to man's genius and will than are plants and machines. But it is possible that the many problems yet to be solved in animal technology obscure the fact of current progress.

The geneticist and his ally, the experimental breeder, have produced livestock and poultry of great practical efficiency, and the nutrition specialist has cooperated to develop means of making meat, milk, and eggs of especial usefulness for food.

This country is freer of serious livestock pests than most countries, and is making greater progress toward a clean bill of livestock health than perhaps any other. The livestock quarantine and meat-inspection services are unexcelled anywhere in their service to both producers and consumers of livestock and livestock products.

Our civilization, like our animal husbandry, is highly artificial, and might decline rapidly without the constant application of research to the problems that are arising. Without the aid and protection afforded by science, disease would speedily result, in all likelihood, not only in a decline in the production of meat and milk and other animal products, but also in a decline in human population, particularly in cities.

Health and security are major objectives of the human race. Domestic animals and their products, with the benefit of man's research and technology, seem to offer increasing aid toward those objectives.

V. INSECT PESTS AND THEIR CONTROL[7]

Insect pests affect man's every activity. They destroy his food plants, his livestock, his clothing, his buildings, and indirectly through insect-borne disease, affect man himself. In the United States alone the annual tax paid to insect pests attacking agricultural crops and livestock often amounts to over 2 billion dollars. The cotton boll weevil, for example, destroys an average of nearly 2 million bales of cotton every year; the hessian fly takes an average annual toll of 48 million bushels of wheat.

Scope of Insect Control Work

The most conservative estimates give the number of insects as about 4,500,000, of which only 750,000 have been described. Not all of these are detrimental to man. Some, such as the honeybee and those which prey on other insects, are beneficial. The destructive and annoying kinds number hundreds of thousands, however.

More than 7,000 species cause economic losses to crops in the United States. The habits and hosts of these all differ and controls vary with the kind of pest, region, and crop. The methods employed include the use of natural enemies, the adaptation of modifications in crop practices, the determination of tolerant or resistant varieties of crops, the use of mechanical devices, the use of poisons, attractants and repellents—in fact any device, material or agency which can be economically applied. In the use of insecticides alone developments in economic entomology have brought the control of insect pests from hand-picking and the sprinkling of a simple insecticide with a whiskbroom to the high-powered sprayers that reach the highest shade trees and the permanently installed spraying equipment by which several hundred acres of orchards can be treated from a central spray plant, and the airplane duster that can cover several cotton plantations in one day.

The field of insect control is very broad. It requires an extensive and specialized technique and the use of detailed knowledge in many fields of endeavor and science. To coordinate and use these effectively to a common end requires detailed planning. There is the intricate technique of rearing the insect to determine its habits, responses, and hosts; the development of ways of producing insect parasites under artificial conditions, of transporting these parasites sometimes half way around the earth, of cultivating these insects as pure cultures, and of successfully introducing them to the field. The work on bee culture requires specialized technique in handling the bees, in studying honey quality, wax production, and the artificial insemination of queens to produce improved varieties. The devising of mechanical and chemical ways of combating insect pests, such as the development of practical traps or new insecticides; improving and adapting spraying and dusting equipment to special agricultural practices and insect conditions;

[7] Prepared by the Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture, Lee A. Strong, Chief.

devising fumigation tanks, steam sterilizers, refrigeration plants, and other devices for treating plants and plant products to free them of insect pests at the ports of entry in order that their introduction may not serve as a means of establishing in this country noxious pests from foreign lands involves the use of highly specialized technique.

Even brief description of the steps involved in developing various methods and planning operations for the control of insect pests would require many pages. Such a discussion would include reference to the principles involved and the technique used in the development of methods and programs; an explanation of the mechanics in making results available for application by individuals and governmental agencies.

The control of insect pests is increasing in complexity. The achievements of the past give assurance of future developments to meet ever-changing conditions. The constant development and change in agriculture and improvement of public health accompanied by the ever-increasing insect consciousness contribute to the complexity of the problem of insect control. The placing of large areas under cultivation and erecting cities and towns have contributed to making favorable environments for insects which in earlier times were of little importance. The rapid development of methods of transportation materially increased the opportunities for dangerous pests being transported to new areas.

The vision of the entomologist is being modified to meet these changing conditions. Lines of investigation little thought of in the early days are under way and basic studies on evironmental influences have been begun. That the work on insecticides will develop materials effective against insects attacking food products without leaving residues hazardous to the consumer seems only a matter of time. Who can say that more intimate knowledge of the environment favorable to grasshoppers will not permit some slight adjustment such as the elimination of some plants favorable in the development of grasshoppers which are of little importance as crops that will prevent general outbreaks of these pests.

Full understanding of the effect of radiations on insects may lead to the development of controls for many pests of households and storages without resorting to control measures now used requiring the application of powerful gases with accompanying health hazard.

VI. WEATHER AND FORECASTS[8]

Weather Forecasting

Weather forecasting, as now practiced by most civilized governments, is of enormous and increasing value to mankind. Great efforts are in progress in America and elsewhere to improve its efficiency and especially to extend the range of forecasts, so that the character of coming months and seasons may be successfully foretold. There is every prospect that this technology will be much more useful a few years hence than it is today. If, however, we are asked to project our view into the more distant future, we must contemplate the possibility that these techniques may diminish in practical value even though they may increase in accuracy.

Half a century ago a vast acreage in the tropics was devoted to growing indigo. The crop was sometimes damaged by drought. Accurate long-range forecasts of droughts might have made these events less harmful to the indigo-grower, though they would still have caused him serious trouble. Today drought has little effect on the production of indigo because it is nearly all made in factories from coal tar. Many other dyes, drugs, perfumes, leather substitutes, and bone substitutes, are now similarly produced. Weather has no influence on their production.

Many more industries may be transferred from the field to the factory and thus be made weatherproof. Transportation by land, sea, and air will be made more and more independent of weather. The discomforts of weather have already been minimized by the artificial control of weather indoors, where most of us spend nine-tenths of our lives. It would seem that, in proportion as mankind becomes less susceptible to the harmful effects of weather, the importance of predicting the latter will decrease, though it may never reach the vanishing point.

Reverting to the present situation, while it cannot be honestly claimed that weather forecasts are now rapidly improving in accuracy, a strongly optimistic feeling that they soon will prevails among meteorologists. This is founded on the fact that methods of forecasting recently introduced are definitely scientific, as contrasted with the empirical methods developed in the nineteenth century.

There have been three stages in the history of weather prediction. In the first, dating from remote antiquity, purely local indications were relied upon to furnish clues to the coming weather at the place of observation. In the second, beginning a few decades ago, charts of weather occurring over extensive areas, drawn from telegraphic reports, enabled forecasters to apply a number of rules, derived from experience,

[8] This section was prepared by the late C. F. Talman, Meteorological Consultant, Weather Bureau, U. S. Department of Agriculture.

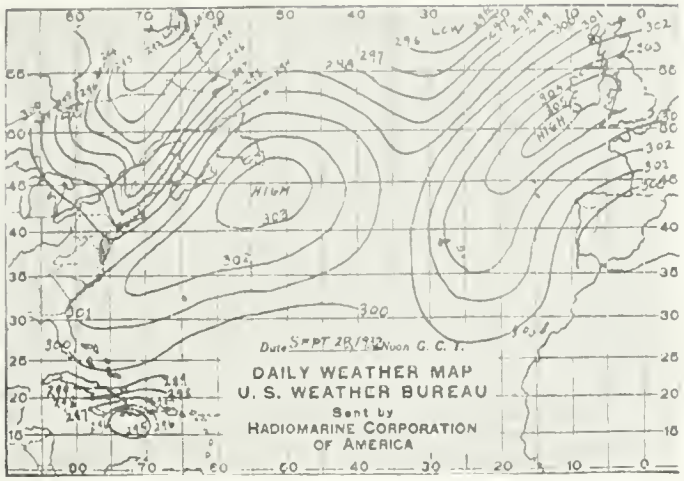

FIGURE 15. Weather map of the North Atlantic Ocean as prepared in New York and transmitted by facsimile radio to a ship in midocean.

concerning the relations of weather in one region to weather in another. The rules frequently failed to work, and the physical principles underlying them were, in general, unknown.

The present era can best be described by saying that forecasting is now being rationalized. The forecast still requires the preparation of a weather map, but on this map it is now customary to mark the locations of so-called air masses, differing from one another in their physical properties—especially temperature, moisture content, and direction of movement—and not merging gradually into one another, but bounded by abrupt discontinuities, called fronts.

The interplay of air currents along these fronts explains the origin of the "lows" seen on the weather map and the distribution of rain, clouds, and other weather conditions surrounding them. Most significant, however, is the fact that the physical factors involved in weather processes, as thus conceived, are susceptible to somewhat exact measurements—derived partly from observations taken, from airplanes or otherwise, at high levels—and these processes are amenable to analysis according to the methods of mathematical physics. Within still modest limits, future weather has become calculable. The whole story of how this has come to pass would take up far more space than is here available.

Attempts at long-range weather forecasting have also entered a new era. Having formerly been regarded, to say the least, as "bad form" on the part of conservative men of science, they are now engaging the attention of first-rate minds in many parts of the world. Some of the methods proposed aim only at a moderate extension—by a few days or a few weeks—of the present range of forecasts. These are in some cases based on weather maps covering a large area of the globe, on which the forecaster watches developments at so-called centers of action, which appear often to furnish clues to following weather in regions remote therefrom.

Many attempts have been made to predict the general character of coming seasons, especially as to temperature and rainfall, from relationships that apparently exist between weather abnormalities in certain parts of the world and the weather abnormalities occurring months later elsewhere. These supposed relationships are called teleconnections, and the degree to which each of them holds good, in the long run, as shown by past weather records, is expressed numerically as a correlation coefficient. A seasonal forecast for any region is based on a combination of several teleconnections applicable thereto that have been found to show high correlation coefficients. The classic example of such forecasting is the official announcement concerning the character of the summer monsoon rains in India, which has been prepared each spring for more than half a century; with, however, only a moderate percentage of successes. It is based on teleconnections extending halfway round the globe.

Still other long-range predictions are founded upon the belief, still unproved, that curves of weather variations, when suitably analyzed, reveal certain regular cycles or periodicities, sufficiently stable to be counted upon to repeat themselves indefinitely in the future.

Probably the majority of meteorologists cherish little hope that these or other proposed methods of long-range forecasting will ever prove successful, except, perhaps, in increasing the present range of predictions

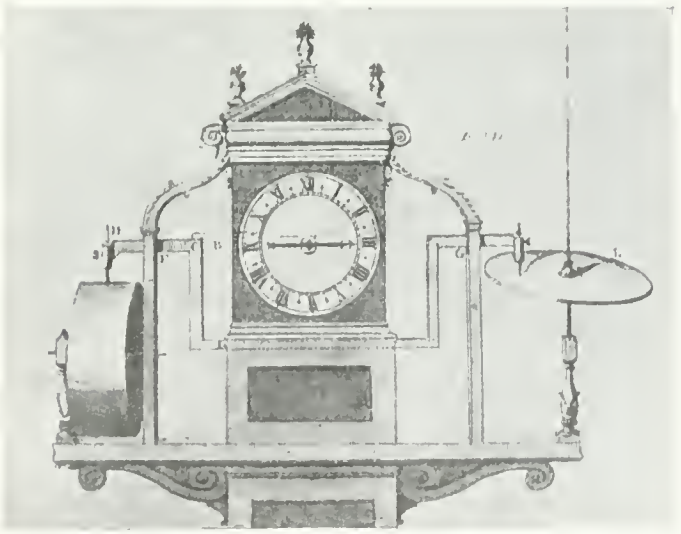

FIGURE 16. Sir Christopher Wren's weatherclock (1663). T. Sprat, in his History of the Royal Society, writes of Wren's invention: "Because the difficulty of a constant observation of the air, by night and day, seemed invincible, he therefore devised a clock, to be annexed to a weathercock, which moved a rundle, covered with paper, upon which the clock moved a black lead pencil; so that the observer by the traces of the pencil on the paper might certainly conclude that winds had blown in his absence for 12 hours space."

FIGURE 17. A modern meteorograph, which makes a continuous record of wind direction and velocity, sunshine and rainfall.

to a slight extent. On the other hand, it is generally recognized that meteorology is under an imperative duty to the public to exhaust all efforts to reach this long-sought goal, unless somebody can demonstrate that its attainment is absolutely impossible.

With respect to this venture the meteorologist is apparently in the position of a gambler who, at the cost of a moderate stake, earns a chance, however small, of winning a colossal fortune.

Weather forecasts, as now issued, though brief in their range and frequently faulty, are valuable to the community because, in an endless variety of ways, people adapt their undertakings to the predicted weather, and in the long run the forecasts are far more often right than wrong. The value of the present forecasts certainly implies that accurate long-range forecasts—even in quite general terms as to place and time—would be correspondingly more valuable in any nation suitably organized for guiding the undertakings of its citizens according to the distant weather program. Forewarned is forearmed. A country can take measures to mitigate the disastrous effects of a droughty summer or a severe winter, if foreseen months in advance, just as it can take steps to repel an alien army that has announced its intention of invading the country.

Weather Recording and Reporting

The vast business of observing weather and interchanging news about it is one of the most spectacular products of civilization. It is estimated that there are in the whole world upwards of 40,000 weather stations—places at which weather is observed, once a day or oftener, with the aid of one or more instruments—as contrasted with a few hundred in existence a century ago. This estimate includes, in addition to fixed stations on land, possibly 4,000 mobile stations on ships, operated according to standard methods under the direction of official meteorological services. Apart from these regular shipboard stations, all other ships enter weather notes in their logs, but the information thus recorded generally remains unutilized by the world at large.

The majority of weather stations are maintained for the purpose of collecting climatic data—statistics concerning the weather conditions characteristic of different localities. Such data are used for three principal purposes; first, in the investigation of meteorological problems; second, in the investigation of the relations between weather and various nonmeteorological phenomena (the relations of weather to health, for example); and third, as a means of anticipating in a general way the weather of the distant future, so that human activities may be planned in accordance.

Climatic data are essentially long-range weather forecasts, and the most trustworthy that we possess at present. Farming operations are planned on the basis of past experience of weather in the region concerned, as embodied in climatic statistics. Travelers for health or comfort go to places where the records of climate show that, in the long run, the most desirable weather conditions prevail. Marine routes and airways are located in accord with similar information.

A few thousand weather stations, besides contributing to the statistics of climate, transmit reports of their observations by wire or wireless telegraphy to centralizing points, and there is a further interchange between these centers. Such reports are intended primarily for the use of forecasters, but they are also used by persons who, for one reason or another, desire information concerning current weather at distant places, rather than forecasts.

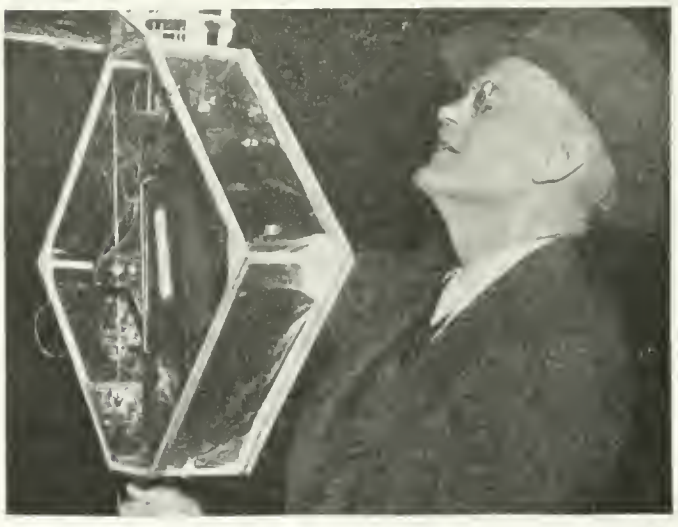

FIGURE 18. A radiometeorograph attached to a sounding balloon. At regular intervals throughout the ascent and drift of the balloon this device reports by radio signals the barometric pressure, temperature, and humidity encountered along its course.

A remarkable international weather news service, operated by means of thoroughly coordinated radio broadcasts, has lately come into existence. One result is that it has become possible to chart current weather, by land and sea, over a large part of the globe. This international system is supplemented by intensive systems of weather reporting in particular areas, especially along airways.

The advent of aviation introduced a new era, in which reports are assembled at brief intervals, day and night, from closely spaced points of observation; and the intensive news service thus developed for the benefit of aviators becomes more and more valuable to the public at large.

A novelty in the transmission of weather news is the use of facsimile radio. This process is employed in a small experimental way for transmitting weather maps and weather bulletins. Hitherto reception of these documents has been limited to a few ships and airships, but as the process is perfected it promises to become much more widely available. It will place weather maps, drawn by experts, promptly at the disposal of many persons who now, when they need such documents, must draw them themselves from the numerical data transmitted in radio broadcasts, a troublesome task and one that, in the average case, is not very accurately executed by the layman. In the United States facsimiles of current weather maps are transmitted by wire for publication in newspapers.

Two other trends in the observation and recording of weather may be mentioned. First is the technical improvement in the compilation of climatic statistics and weather records and their subsequent utilization through the use of tabulating machines (the "punch card" system). Second, the geographical distribution of weather and climate is now registered in certain regions and for particular purposes at numerous points separated by very short horizontal and vertical distances; as short, in some cases, as a few feet. Such procedures are classified under the terms "micrometeorology" and "microclimatology." They are employed, for example, in determining consistent differences between the minimum temperatures occurring at a given time at different points in a fruit-growing area. A horticulturist may adapt a general prediction for such an area to his own orchard or particular parts thereof, and thus make economical use of orchard-heaters as protection against frost. A number of analogous "temperature surveys" have been carried out for other purposes, and there have been intensive studies of the local variations of wind, rainfall, and other elements.

"Robot" Weather Observers

The substitution for the human weather observer of an instrument that makes a continuous or intermittent automatic record of one or more meteorological elements is hardly a new development, since one of the earliest instruments of this character was the "weather-clock" devised by Sir Christopher Wren in 1663. Such instruments came into extensive use in the latter half of the nineteenth century. In more recent years a number of instruments, known as radiometeorographs, have been introduced for the purpose of transmitting automatic records of meteorological conditions by radio. These reports in some cases are automatically registered at the point of reception. Heretofore this system of reporting and recording weather has been employed chiefly in connection with the flights of sounding balloons, but the same method can be used for obtaining reports from places at ground level where it is not feasible or convenient to maintain human observers. A few installations of this character already exist.

We may expect to see the existing vast network of weather stations greatly enlarged in the near future by means of these devices. It has been proposed to attach some of these "robot" stations to buoys anchored in shallow portions of the ocean or to beacons, analogous to lighthouses, high enough to protect the instruments from disturbance by waves. Others will probably be placed on islands, and still others on mountain tops.

Lastly, a plausible plan was worked out a few years ago to install some of them (dropped from an airship) on drifting ice in the polar seas. In this case the drifting station would be operated in connection with two fixed stations on neighboring shores from which, by means of radio bearings, its position could be obtained at the time of each report. The radio transmitters of such stations are operated by storage batteries. It is claimed that some of those already designed will be able to operate three times a day for a period of 2 years without renewal, and to function at the low temperatures of the polar latitudes.

Whatever advantage accrues to mankind through the maintenance of weather records at numerous points on land and sea should increase in proportion as the use of this new procedure becomes more general. One of its promising applications is as a means of securing reports of barometric pressure now urgently needed in the oceanic areas subject to tropical hurricanes to supplement the somewhat meager radio reports received from ships.

Controlling Atmospheric Environment

The subject of controlling the atmospheric environment and of the physiological benefits likely to result therefrom is enshrouded in controversy. Nevertheless, a number of facts that have lately come to light seem to suggest future possible developments that, in their

value to mankind, may throw into the shade all other applications of meteorological knowledge.

The perennial dream of controlling outdoor weather is not likely to be realized, except on a small and local scale, short of some millennium of unlimited scientific achievements. On the other hand the control of atmospheric conditions indoors—which began when primitive man built a fire in his cave to keep him warm—has recently made startling progress.

Indoor climates are now modified at will, within wide limits, for the promotion of health and comfort, with respect to temperature, humidity, air movement, and the amount and quality of light. This is true not merely in the dwellings and workplaces of mankind, but also in ships, railway cars, and other vehicles. Indoor atmospheres are kept clean and germ-free. Interesting experiments have been made in regulating their electrical condition (ionization) and some serious investigators claim that the "freshness" of air can be thus maintained, and even that the process can be employed successfully in the treatment of disease. Lastly, it is conceivable that the chemical composition of indoor air may be altered to the advantage of the health and efficiency of those who breathe it.

VII. SOIL: ITS USE AND CONSERVATION[9]

Utilization

Major developments in fertilization, liming, tillage, drainage, irrigation, and erosion control methods have their roots in western Europe as recently as 200 years ago. Slightly earlier, advanced minds attempted to arrive at the "Principle of Vegetation", with conflicting results as testified to by the theories advocated for water, saltpeter, air, fire, and fine earth.

The fallowing of one-third of the land was a long established feudal practice because of the low productivity of the soils for grain. Owing to the insistence of Jethro Tull, inventor of the drill and horse hoe, that cultivation of the soil was imperative for plant growth, a change in methods preceded a change in crops. His teachings were accepted to the extent that turnips were introduced to facilitate cultivation of the soil given to grain production. As turnips were best utilized as feed for livestock, increased numbers of livestock furnished an increased manure supply. Yields increased and more livestock were kept. Grasses and legumes were introduced, and a succession of crops known as the Norfolk system supplanted the fallow system.

This change from a system of grain following grain with every third year in fallow to one of a rotation of crops doubled wheat yields, from 10 to 20 bushels. It was an important revolution in agriculture. Commercial fertilizers were as yet unknown. They are not to be confused with the liming and marling practiced under the Norfolk system.

Fertilization, by other than animal manures, owes its development largely to Liebig who in 1840 in a report upon "Chemistry in its Application to Agriculture and Physiology" denounced and eventually killed the humus theory which stated that plants obtained carbon only from the soil. Believing that plants obtained a sufficient supply of carbonic acid from the air, Liebig introduced the mineral theory which stated that plant growth was related directly to the quantity of mineral elements in the soil. This doctrine gave added impetus to the "Balance Sheet" theory of nutrition which owed its beginnings to the careful experimental work of Boussingault who had conducted research on his farm in France upon the gain and losses in soil nutrients under various rotations.

Lawes and Gilbert at Rothamsted at a later date pointed out that the ash content is not a reliable index to the nutritional needs of a plant. Contradictory results with the nitrogenous requirements of plants when legumes were included troubled investigators until after the rise of bacteriology. The development of bacteriology and its agricultural applications form an interesting chapter of agricultural history.

Relation to Nutrition

With the progress of time the scope of investigations upon the questions of fertilization and technique of application have become more profuse and interlocking. Studies on the availability of phosphates and potash, the roles of the minor elements in nutrition, effect of placement of fertilizer in relation to seed and growing plant, recognition of physicochemical processes in soil and plant colloids, realization of inherent differences of productivity in soils for plants, combined with questions of the economic feasibilities of practices, illustrate some of the branches of current fertilizer science. Recent trends of interest in fertilizer practice extend beyond the plants to the health of the animals and people who eat them as affected by their composition. Especially is this being considered in the dairy industry with studies in pasture fertilization. It appears probable that in the future certain physiological and morphological differences among mankind from various geographical regions may be explained by nutritional differences which in turn may be explained by differences in the

[9] The first part of this section (Utilization) was prepared by J. K. Ableiter, Senior Soil Technologist, Bureau of Chemistry and Soils, U. S. Department of Agriculture. The second part (Erosion Control) was prepared by Leland Barrows, Special Assistant, Soil Conservation Service, U. S. Department of Agriculture.

availability of the plant nutrients occurring in the respective soil types of those regions. Thus scientific research will continue to study the soil-plant relationships which center about the phenomena of plant feeding in the localized areas of contact between the root hair of the plant and the colloidal particle and solutions of the soil. Definite practices in fertilization will attempt to meet the individual needs of plants and soil types for particular chemical nutrients. The importance of the form, availability, and concentration of phosphate fertilizers will be stressed, as will also the economic advantages of higher concentrations of mixed fertilizer. The role of minor elements in nutrition will become important as more nearly pure chemical fertilizers are placed on the market.

With the establishment of the role of bacteria in soil fertility and their soil requirements, liming became more vital to successful farming on the acid soils of western Europe and eastern United States. Studies of soil acidity led to arbitrary methods for the determination of lime requirement and opened wide the field of investigation on the phenomenon of base exchange and the mineral constituents of soil colloids and base-exchange material. Indeed the conflicting data and theories of today concerning the structure and composition of the colloidal soil complex challenge the investigator, and it is not too much to expect that future scientists will be enabled to comb out the tangled skeins of evidence now presented and formulate a more intelligent management of individual soils.

Tillage, as a technique, has been improved consistently since the days of Tull. Straight and deep furrows and finely conditioned seedbeds had been the criteria of good farmers, without question, until these practices of the native forested areas were carried onto the drier grassland areas where a different climatic regime and different soils demanded other practices.

Problems of Land Use

After the opening of the grasslands to settlement, came power machinery suited for extensive operations. Only recently have manufacturers and financiers realized that economic and social stability was threatened by optimistic high-pressure salesmanship in these open grasslands which beckoned so promisingly. Changing points of view on tillage are evidenced by the discard of the dust-mulch theory. Sweeping generalities are being amended, and practices are being made to conform with climatic and soil conditions and economic trends. Tillage practices, land utilization, and social tenure of land are closely interwoven. The future gives promise that science will be permitted to develop programs of wiser land-use throughout the Nation, particularly in the Tennessee Valley and in the semiarid regions where past practices have proved to be economically hazardous. However, the tremendous social implications decree that time is needed to make the necessary voluntary readjustments.

The soils of western Europe and eastern United States have common characteristics, in that they are relatively low in inherent productivity, are acid, are low in organic matter, their structure is easily destroyed, and they did not lend themselves readily to agriculture in their native forested state.

The efforts to increase their productivity were made by men who looked on the soil as a static and unchanging medium deficient in one or more components, as compared to an ill-defined standard of perfection. In certain ways these efforts may be looked on as a study in soil pathology. Thus, much research was given to the study of the chemical and textural compositions of soils without a consideration of their genesis or evolution, other than as geological material containing certain and lacking other specific elements of nutrition which could be corrected through the techniques discussed.

Relative to the influences of the present techniques on the future developments in agriculture, it is essential to note the rise of pedology in Russia and the influence of its teachings on the scientific thought of soil technicians and agronomists in the western world. This science considers the soil as a natural body, dynamically responsive to the environment of which the active factors for soil development are the climate, the vegetation, the relief, the age or length of time the environment as such has been active, and the parent material. Although it is recognized that the marked characteristic of the soil is its productivity for plants, the soil is not looked on exclusively as a medium for plant growth, but rather as a distinct entity whose physical and chemical characteristics have been shaped by an accord with the environment. Hence the soil of a specific area is not lacking, according to some standardized concept, but is the accompaniment of a certain environment with a characteristic inherent productivity for certain plants.

Accordingly soils are studied as objects in themselves, and differences in the structure, color, depth, and texture of the various horizons are noted. This has led to the establishment of soil types, defined by certain physical and chemical characteristics which have been developed by the environment. It follows necessarily that soil types are limited in geographical extent, according as one or more factors of the environment may change. This newer concept carries the thought that all techniques of crop and livestock production are ultimately concerned with specific soil types as units of the landscape, having

a distinctive profile, native vegetation, range of relief, drainage, response to fertilizer, inherent productivity, adaptations for crop plants, and other features.

One of the technological trends of the future appears to be the more exact mapping and study of these land units, or soil types. Research will be conducted on their chemical, physical, and biological characteristics as they pertain to crop plant growth and production. This means further intensive study in the laboratory, experimental plot, and the farmer's field, along such lines as colloidal characteristics, soil-moisture movement and availability, soil structure, chemical constitutents, and response to certain treatments and managements. The inherent productivity and the response to amendments of the individual soil types for specified crops will become current knowledge among agricultural workers. The extension of fundamental data and experience depend on classification of the soil on the basis of land units which may be given geographic extension. The study of plant adaptations will renew and continue interest in the biological sciences. Plant physiology, ecology, genetics, and pathology will be emphasized, as will colloidal chemistry and biochemistry.

Erosion Control

The problem of soil conservation is inevitably involved in any agricultural development. Breeding or introduction of a new crop may alter the balance of agriculture in wide areas. Its production may require new and, to the soil, hazardous methods of cultivation. It may open new regions to the plow. Thus the introduction and breeding of new drought-resistant varieties of wheat made profitable the cultivation of thousands of acres of western prairie land, with a resultant tremendous increase in the hazards of wind erosion during times of drought. New implements, new systems of cultivation, and new methods of processing, storing, and transporting crops may similarly alter the nature of agricultural production and its effect on the soil.

Except on the relatively small areas of perfectly flat land any form of agricultural development, however primitive, speeds up the process of erosion. There is ample evidence that erosion was an important factor in the destruction of primitive civilizations whose agriculture never progressed beyond the stage of the ox-drawn plow. But technological developments affecting the soil have not been all on the debit side. The same large tractors that turned the virgin sod have been used to build terraces to conserve the rainfall and the soil. Plant exploration and scientific plant breeding have discovered and developed plants that protect the soil as well as those that expose it. The same engineering skill that was used to drain the prairies of the upper Mississippi Valley now is used to build terraces, check-dams, and farm reservoirs.

In short, if technology has brought problems it has also brought knowledge and skill with which to help solve them. Technological development affecting agriculture, although it may have increased the rate at which new land has been affected by erosion, probably has not altered in the long run the fundamental effect of agricultural activity upon the soil. Perhaps there are a few exceptions to this statement. Large-scale lumbering, made possible by the use of machines and made profitable by our tremendous industrial development, probably has wrought irreparable damage to much forest land. But it is generally true that cultivated soil is exposed to the erosive forces of wind and water with substantially the same effect whether the cultivation is by ox-team or gang plow.

But pressure of necessity makes agriculture naturally an exploitive process. The spur of hunger and want stimulates production. Conservation develops when it becomes apparent that only on the basis of conservation can production be permanent.

The application of scientific methods to the study of soil erosion and its control is a recent development. Prior to 1929, when the first erosion experiment stations were established, a few pioneering State colleges and experiment stations had investigated the subject but most knowledge of it has been gained incidentally. The first understanding of the widespread incidence of erosion was gained by soil scientists engaged primarily in the survey and classification of soils. Foresters were investigating the importance of forest cover as a protection to the soil and the occurrence of disastrous soil washing as an aftermath of destructive lumbering practices and forest fire. A few exceptional farmers had taken adequate steps to prevent soil washing.

In the papers of both George Washington and Thomas Jefferson are letters to the managers of their estates urging such practices as the filling of gullies with brush and straw and plowing across the slope rather than up and down. In certain Pennsylvania communities strip-cropping and the leaving of grass waterways through cultivated fields are traditional farming practices—with readily apparent benefit to the soil.

The practice of building a system of hillside ditches or terraces in cultivated fields developed in the South more than half a century ago and has spread throughout most of the Southern States east of the Mississippi. Most of these early terraces were built without engineering knowledge, and without a full understanding of their limitations. As early as 1890, after an effort to improve the terraces then in use, Priestly Mangum developed the now famous Mangum ter-

race. Even until comparatively recently, however, scientific study of soil conservation had not progressed far enough to prevent the widespread construction of terraces improperly designed to carry the run-off of the fields and improperly related to agronomic practices necessary to make them effective. Thousands of acres too steep and too erosible for any type of clean-tilled cultivation were terraced and planted to cotton.

As the first studies of the problem of soil were generally incidental to other research and were carried on by engineers or foresters or soil specialists, they were for the most part limited by the professional horizons of the men and agencies conducting them. To a large extent, we still have an engineer's, a forester's, an agronomist's, a soil specialist's approach to the problem of soil conservation.

As the scientific study of soil erosion progressed it became increasingly apparent that a synthesis of these divergent viewpoints was necessary. A technique of soil conservation was needed. Out of the knowledge of every scientific discipline which could contribute, from the technique of every agricultural profession which could be made to play a part, a coordinated plan of soil conservation is being built.

Since 1933, when the Soil Erosion Service (now the Soil Conservation Service of the U. S. Department of Agriculture) was established, there has been a tremendous expansion of work in soil conservation. New techniques have been developed and old ones tested and applied on a scale never before attempted. During the last 3 years great strides have been taken toward a synthesis of new points and plans. A coordinated attack on the problem of erosion has been developed and applied under a wide variety of conditions. It is bringing the resources of agronomy, forestry, engineering, and soil science together in a unified, integrated program of erosion control.

It is not too early to say that the concept, if not the final methods, of scientific soil conservation has been established, tested, and proved. This development of an integrated approach to the study and control of erosion is the most important technological advance in the field of soil conservation.

The essence of the coordinated plan of erosion control, as practiced by the Soil Conservation Service, is flexibility. The aim is to treat each farm and field in accordance with its individual needs and adaptabilities. Reliance has been placed on no single technique. Instead, the soil conservationist has utilized every available method in his program. Most of his actual technique can rightly be claimed as the development of some older agricultural profession. Stripcropping, terracing, contour cultivation, range and pasture management, forestation, gully control, and many other practices have essential places in a coordinated erosion control program.

The significance of technologies which will provide economical and adequate conservation of soil cannot be easily overstated in terms of social advantage. The wastage of soil is wastage of the basic asset on which society depends.

VIII. CHEMICAL FERTILIZERS[10]

The cultivation of plants for sustenance dates from the remote past. In the course of ages, knowledge was gained fortuitously that the growth of vegetation was promoted by the addition to the soil of certain materials and that the continued raising of crops without such additions frequently resulted in decreased yields.

Although the Romans were aware of the social, economic, and political significance of such soil deterioration, little or nothing was known of the principles of fertilization until the early years of the nineteenth century. With the understanding of these principles came the birth of the fertilizer industry which at first dealt in naturally occurring materials and various animal and plant wastes, later supplemented by the byproducts of other industries. The modern chemical fertilizer industry began with the discovery in 1840 that the fertilizing value of bones was increased by their treatment with sulfuric acid and with the commercial application thereof for the production of dissolved bone and superphosphate.

Commercial mixed fertilizers are mixtures primarily of materials that contain the three fertilizing elements, nitrogen, phosphorus, and potassium. Until comparatively recent years, the United States was largely dependent upon foreign sources for its nitrogen and potassium and was self-sufficient only as regards phosphorus. Our enormous deposits of phosphate rock, which for years not only met our own demands for phosphorus for fertilizer purposes but also supplied those of many European nations, still suffice for all our anticipated needs in the near future. As a result of technological progress, a synthetic nitrogen industry, based on the utilization of the inexhaustible supply of the nitrogen of the air, has been developed, the capacity of which, together with our byproduct nitrogen capacity, is capable of expansion to supply all future needs, whether for fertilizers or explosives. The dearth of potassium during the period of the World War, resulting in a thousandfold rise in price, stimu-

[10] This section was prepared by A. R. Merz, Chemist, Bureau of Chemistry and Soils, U. S. Department of Agriculture.

lated a successful search for native deposits of potassium salts. The discovery of large natural beds of these salts, coupled with the development of procedures to exploit them, and other sources of potassium in this country, has freed us from dependence on foreign monopoly for this element also.

Supply Problem Arises

During the early years of the fertilizer industry the materials that were available to the fertilizer manufacturer for use in the production of commercial mixed fertilizers contained relatively little of the three elements considered of primary importance. The mixtures prepared from them were necessarily low in these elements. Low-grade materials, however, are characterized by high costs of transportation and handling relative to their plant-nutrient content. This disadvantage to their use resulted in a gradual increase in the concentration of many fertilizer materials that were already in use through improvements in methods of manufacture and the introduction of refining processes. With increasing consumption of commercial fertilizers and the resultant growth of the fertilizer industry, the more serious question of supply arose. A number of materials extensively used, such as cottonseed meal and tankage, were more and more diverted to use as feed for stock. In addition, the output of the industrial byproducts that found use in the fertilizer industry was dependent on the sale of the principal products and could not be increased independently to meet increased demands for the byproducts. The increased demands for fertilizer materials have therefore been supplied more and more by high-grade chemical products.

A corresponding increase in the concentration of the mixed fertilizers did not occur. The primary reason is the fact that the various grades of mixed fertilizers had become established when low-grade materials only were available and farmers continued through conservatism to demand these grades. Fertilizer manufacturers were compelled, as they gradually substituted higher grade for lower grade materials in the preparation of their mixtures, to use increasing quantities of inert materials or fillers to obtain the grades demanded. The chief causes for such rise as has taken place were (1) efforts of the manufacturer to sell higher grade fertilizer mixtures rather than to add increasing quantities of filler to his mixtures, (2) the educational campaign of agronomists and other officials of various agricultural experiment stations and of the United States Department of Agriculture to bring to the attention of farmers the savings accruing in the purchase of higher grade fertilizer mixtures and (3) the passage of laws in a number of States prohibiting the sale of fertilizers containing less than a minimum quantity of plant nutrients, a result of the efforts of the same officials. Nevertheless, mixtures containing double the content of nitrogen, phosphorus, and potassium in the fertilizer mixtures ordinarily sold can be readily prepared by the use of materials that have been made commercially available. Also, to meet the former objection that fertilizer distributors could not apply uniformly in the field the lesser quantities of such higher analysis fertilizers that would be required to supply the same quantities of plant nutrients, distributors have been devised capable of uniformly applying as little as 50 pounds of fertilizer per acre.

More Reliance on Chemistry

Failures to obtain favorable responses on some soils when mixtures of only nitrogen, phosphorus, and potassium are used have brought forcibly to attention the fact that plants require for their growth other elements also and that certain soils may be so deficient in one or more of these "minor plant foods" as to limit the size of the crop obtainable. As the fertilizer industry of the future relies more and more for its supplies of fertilizer materials upon products manufactured by chemical processes, increasing consideration will have to be paid to providing the secondary fertilizing elements in mixed fertilizers. This will have an influence in limiting the ultimate concentration of higher analysis fertilizers as regards the primary fertilizing elements. Although most fertilizers of the present day supply more calcium and sulphur than are needed on the majority of soils, large areas of our lighter soils would, within a comparatively short time, develop calcium and sulphur deficiencies if these elements were omitted from fertilizers. The addition of compounds of magnesium and manganese to fertilizer mixtures has already become quite extensive. Recent experiments have shown that the application of small quantities of other elements such as copper, zinc, and boron to certain soils considerably increases the crop yields thereon.

In consequence of the growing use of synthetic ammonia and ammonium compounds in fertilizers, attention has also been directed of late to the fact that fertilizer mixtures containing nitrogen in such forms only tend to make soils more acid in reaction and that continued application thereof finally causes the soil acidity to reach a point that affects growth of crops adversely. A method of calculation has been developed for determining the potential acidic or basic reaction of fertilizer materials. By use of the values thus obtained, fertilizer manufacturers can know in advance the potential reactions of their various fertilizer mixtures. Extensive progress has been made toward the production of mixtures that are non-acid-

forming, particularly by the use of ground dolomitic limestone. The increasing necessity for use of neutralizing agents as well as need for provision of secondary plant-nutrient elements are factors that will probably limit the ultimate concentration of fertilizer mixtures as regards the three primary elements to the double-strength mixtures. Such mixtures, so adjusted as regards potential acidity or basicity and containing the secondary fertilizing elements best adapted to the particular soil and crop for which they are intended, will probably constitute the greater proportion of the fertilizer mixtures of the future.

Techniques of Application

Recent work has shown that the maximum benefits obtainable from the use of fertilizers are frequently not attained because of improper methods of application. Proper placing of fertilizers with respect to the seed both as regards closeness and relative location has been found to considerably enhance the increased yields. Too close proximity of a fertilizer to the seed is usually the sole cause of delayed germination, or even failure to germinate, as well as of injury to the young plants. The usual method of mixing the fertilizer with the soil in the row, practiced in many localities, is frequently a poor one. Methods of application best adapted to the different types of soils and kinds of crops are being gradually learned, and the knowledge thus acquired is being used for the designing of new fertilizer distributors and attachments, the increasing use of which is certain to enhance the average yields now obtained per acre with the use of fertilizers.

Prevention of the segregation of the materials contained in mixed fertilizers that occur during the handling processes between the fertilizer factory and final lodgement in the soil is receiving attention. The extent to which this segregation takes place increases with differences in the sizes and specific gravities of the individual particles of the materials used to prepare the mixtures. As a result of segregation the composition of the mixture ceases to be uniform throughout so that, when the mixture is applied in the field, the same relative quantities of the different fertilizing elements do not become accessible to the roots of the individual plants. In consequence, a given plant may have at its disposal more of one of the fertilizing elements than it requires while it is not supplied with enough of another element for its full development. Methods of granulation have recently been devised which not only prevent segregation but also reduce the tendency of the mixtures to cake or become sticky and facilitate the process of their distribution to the soil.

Developments and improvements of fertilizers in the future have many important possibilities. Nationally, we have become self-contained as regards the elements on which we are dependent for the production of our future crops. As a result of new and cheaper methods of manufacture, the cost of these elements in fertilizer materials has been considerably reduced. Further savings are possible by using these fertilizer materials for the production of double-strength fertilizers. The employment of such double-strength mixtures, granulated, properly placed, and suitably adapted in composition to the soils and crops to which they are to be applied, will considerably increase crop yields per acre per unit of fertilizing element employed. The use of fertilizers will thus be made more profitable and their more general employment and in larger quantities per acre will result. The increased yields per acre obtained will encourage the withdrawal of lands now unsuited to cultivation and their sowing to grasses or their reforestation, and an intensification of the cultivation of the better suited lands with greater consideration given to the conservation of their fertility. In many farming sections the development and maintenance of pastures on the poorer land, with the aid of fertilizers, and cultivation of only a small portion of the land, will necessitate the expenditure of less labor on the part of the farmers in proportion to the financial returns.

IX. MARKETING PRODUCTS[11]

Within virtually the space of a lifetime we have changed from an agricultural to an urban-industrial Nation. This transformation has necessarily revolutionized the methods of marketing farm products in the United States. No longer face to face on market days the farmers and consumers see most products pass through many channels and processes between the farm and the home. The next lifetime seems destined to witness the improvement, adaptation, and extension of the techniques and equipment now at work rather than any dramatic change.

Development of Vast Marketing Machinery

Development of different kinds of market places is one of the outstanding advances. The kinds of markets have changed with changing years, but many of the earliest American markets still exist. Our present market places range from small uncovered local curb markets, through the large city or municipal markets

[11] This section was prepared by Caroline B. Sherman, Associate Agricultural Economist, and Carl H. Robinson, in charge Division of Cotton Marketing, Bureau of Agricultural Economics, U. S. Department of Agriculture.

of earlier days, to the newer great terminal markets and outlying regional markets for receiving and redistributing motortruck receipts. Ownership may be public or private. Methods, technical equipment, regulations, and authority vary with the markets—from the antiquated to the most modern. Then there are the exchanges and the auctions. Branch and chain stores with their accompanying problems are among the newer developments.

Methods of marketing or shipping from the farm vary correspondingly. A relatively few farmers still market direct by wagon, motorcar, or motortruck. Others still act as their own salesmen on the local market. Others sell from roadside stands or by parcel post. The old personal relationships between the consumers and those who supply their wants die hard.

A large and increasing number sell through intermediaries of many kinds. Some find the methods involved in such selling satisfactory and some do not. Most farmers feel that the complicated systems are necessitated by modern conditions and demands. They may deplore the mechanized and commercialized methods but they expect an increasing proportion of the farm commodities to be marketed through these channels. They want the channels kept clear and open, they want them improved, and to a certain extent they want them regulated.

Service to Improve Entire Marketing Machinery

Federal and State agencies have been working to those ends actively since 1914, when a wave of interest in costs of living and costs of distribution reached a crest. Subsequent improvements in the marketing mechanism include the Nation-wide system of standards for practically all farm products, formulated by the Bureau of Agricultural Economics and now widely used, the shipping point and market inspection service, the Nation-wide market news service on farm products, the agricultural outlook service, and educational regulatory services, both State and National, that tend to improve the ethics and the technique of marketing.

Techniques involved in these services are many, varied, and ingenious. Each service could tell a technological story in itself. In each case the service, soon after being inaugurated, has become virtually an indispensable part of our vast marketing machinery.

Transportation and refrigeration, among the chief technological advances that have aided this revolution, are treated elsewhere in this report. The importance of their part in past, present, and future could scarcely be overemphasized. Among recent notable transportation developments in marketing is the use of the motortruck. Marketing advantages and disadvantages attend its growing use. Direct buying of hogs, a vexing and unsettling question, is an example of the attendant developments.

At present the most rapid technological changes and advances in marketing practice are found in the field of freezing and refrigeration. With adequate refrigeration available to a rapidly increasing number of households the use of frozen products will expand rapidly. The subdivided refrigerator car is coming into use. The three box-like containers on one flatcar can be placed on three separate trucks and sent to small towns or dealers not readily reached by railroads or not needing full carlots, or to summer resorts. Railroads are being asked to provide for re-top-icing in transit. Presumably this means reduction in rate of melting and consumption of ice. In sort, we may be passing out of the "glacial period" of marketing.

There are obvious advantages in preparing a frozen product in consumer packages. Frozen products are not to be regraded or resorted. There are different grades of the product and they will probably be stated on the package.

Progress in the development of canning of foods has been marked and there is now a promising tendency toward informative labeling of canned goods. The marketing of carefully graded and accurately branded frozen foods may accelerate this tendency in the canned goods industry.

Farmer Cooperation in Marketing

Besides the farmers who sell direct and the farmers who sell through middlemen, we have the cooperative marketing of farm products by groups of farmers. Cooperative marketing in this country has reached huge proportions. These cooperative organizations vary from simple associations to large and complicated bodies employing most of the techniques of the usual commercial marketing but employing them for the benefit of the farmer members.

The cooperative marketing idea now seeks primarily to eliminate certain so-called wastes in the marketing process. The principal difference between the chain-store idea and the farmers' cooperative today is the direction of integration. The chain-store integration proceeds from the consumer back to the producer while the cooperative-marketing scheme integrates from the producer forward to the consumer.

It is impracticable in a short space to examine these two methods and appraise their effectiveness. Both have had influence in changing the marketing of farm products during the last 20 years, and upon the elimination of some physical waste and unnecessary costs in the process. Their future relative strength will depend largely upon their relative services to society as a whole.

Technological Improvements in Marketing and Distribution

Technological improvements in marketing have aided farmers in disposing of their products and consumers in obtaining food and fibers that more nearly fit their wishes and pocketbooks. Most of them probably were designed to more nearly satisfy the consumers' requirements. Many have lowered or will lower the costs of both food and clothing. Some have added to living costs. Many, but not all, are socially desirable. Nearly all have arisen out of or are related to the growing complexities of our American life.

Some of the specific techniques developed in channels of marketing and distribution may be illustrated in a discussion of technical developments in the marketing of cotton. In this respect cotton is perhaps classic. For the sake of brevity this discussion will be restricted chiefly to developments in which the United States Department of Agriculture has had a part. The developments occurring within the limits of a short lifetime will be discussed, principally.

Parts of other sections, especially the one on dairying, touch on other marketing improvements and changes. In general the techinques developed in marketing and distribution channels for cotton, as well as for other farm commodities, include the following: (1) Improved techniques in methods of harvesting and preparing products for market which may conserve labor, improve quality, and lower costs; (2) use of uniform standards to facilitate grading and expedite distribution of various qualities of products through the numerous channels from producer to consumer; (3) provision for and improvements in existing techniques of grading, inspection, and regulation of the distribution of most important farm products; (4) standardization and the development of new types of containers for products moving through marketing channels—in some instances with standards for different containers for farmers, wholesalers, and retailers; (5) improvement of business and accounting systems all along the line, and (6) developing and designing new uses for agricultural products.

Farmers Adopt New Techniques Slowly

Mechanical inventions usually require years of trial before their general acceptance and use. The same is true of new techniques in marketing and distribution. In cotton marketing, as in cotton production and manufacturing, new and old techniques may be observed in use side by side. The one-horse plow and the tractor may be seen in adjacent cotton fields in the Southeastern States. Cotton is still sold in the seed in some local markets, with only the most general reference to quality in pricing, but across the street, at the same time, in the same market, farmers may be selling lint cotton in bales, on the basis of accurate quality classification and receiving payment on the basis of central-market premiums and discounts for quality. One-horse wagons and up-to-date trucks are both used to transport cotton to the same local markets in the Cotton Belt. Likewise in cotton manufacturing it is not unusual to see equipment of the latest design cleaning, spinning, winding, and weaving in a mill which also has machinery bought 10 years ago performing similar functions. Perhaps new techniques are adopted too slowly, but care in adoption of the new is often economically and socially desirable.

The basis for a much more nearly perfect marketing mechanism for cotton is gradually being built, but there have been no quick changes, nor are they likely to occur. The development of techniques and information is always considerably in advance of their general utilization by farmers for whom they are primarily designed. For example, it is now possible for most farmers to be much more fully informed relative to the supply and demand conditions for cotton than formerly and at little or no cost to the individual. It is possible for a great many more farmers to plant improved varieties of cotton than actually do plant such varieties. Facilities are available for supplying information on the quality of more cotton before it leaves the farmers' hands than is actually classified.

Resistance to change on the part of both farmers and cotton buyers is perhaps the greatest obstacle to be overcome. The resistance of one group may have a different base from that of the other, but both frequently react against farmers and sometimes against buyers. This lack of complete effectiveness is perhaps due in part to a lack of facilities to demonstrate effectively the advantages of using new techniques and the results of the development of new techniques, such as information on varieties, quality, and supply and demand conditions for cotton.

Farmers Confronted With Many Technical Questions

Beginning at the farm on or before planting time, farmers are confronted with such technical questions as the following: How much of the various qualities of cotton should be produced to obtain the largest net income? Where can seed of tested cotton varieties be obtained, possessing fairly stable known qualities for planting, such as those developed through years of technological experimentation and technical research by State and Federal agencies? How many times should cotton be plowed, hoed, and picked, so as to obtain a maximum net income? What type of cotton gin should be patronized? Should cotton be sold in the seed or in the lint? How can the quality of lint cotton be accurately ascertained? When is the

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most advantageous time to sell? Many of these questions obviously must be answered by the individual farmer.

The marketing mechanism—which is so closely related to the economics of production that the technological phases of the two cannot be separated—can undoubtedly be improved a great deal more in the years to come. The foundation for much of the work in improving cotton marketing and decreasing distribution costs has been well laid.

For example, through such technical developments as the crop meter (a device attached to an automobile that is driven along the highway to register the extent of a "sample" area planted to cotton) the accuracy of crop estimating has been increased. This, of course, is a mere detail in the recent improvements in the techniques of the elaborate governmental system of crop estimating, reporting, and forecasting. Improvements in this work have made it possible for most farmers to obtain the information regarding supplies of cotton comparable to that possessed by the largest commercial concerns. Estimates are also made of the quality of cotton carried over each year and of that ginned during each season and some individual farmers have been furnished with information regarding the grade and staple length of each bale of their cotton. Other similar information is available but the accuracy and comprehensiveness of such data are being improved yearly. Plans are continually being devised to improve the techniques of distribution for various kinds of information needed by farmers and as a corollary to these changes will go a type of information that will more nearly fit local needs.

Quality is a basic factor affecting demand and through the development of a wealth of techniques and devices our investigators are learning much more about the character as well as the grade and staple of cotton than had been previously known. This work is basic to improvements in the accuracy of quality measurements and to necessary revisions in standards for the grade and staple of American cotton. Along with improvements in the standards for quality and in classing will go changes in the techniques of supervision and instruction for qualified cotton classers, so that the accuracy of this work will be further improved. It is not improbable that the techniques developed in the field of quality measurement and practical grading and classing will eventually lead to an accurate classification of the entire cotton crop before it is sold by growers. As an additional definite practical step, an identification device was recently invented which may make it possible to maintain the identity of cotton bales in marketing channels. The general adoption and use of such a device would facilitate the use throughout the marketing chain of an initial classification of the cotton and would tend to simplify marketing procedures.

Official Standards for American Cotton

Because of the many improvements in the cotton-marketing system that may be visualized but have not yet been adopted too much emphasis can easily be placed upon probable future developments. Outstanding among the technical developments that are now in general use are the standards for American-grown cotton, promulgated by the United States Department of Agriculture. These standards are represented by practical forms for both grade and staple. As a result of the suitability and reliability of these standards, the world buys American-grown cotton largely upon American standards, which have thus become the universal standards for the grade of American cotton. The reliability of these standards has meant economic savings within the field of distribution and has aided in stabilizing and reducing the complexity of marketing machinery and made possible more accurate price quotations for cotton.

Cotton-Drying Machinery Developed

Improvements in the technique of preparing cotton for market are expected. For example, new drying machinery has been developed for the drying of seed cotton before ginning. Ginning techniques are being improved in many ways. Increasingly precise and scientific knowledge of fibers made possible by ingenious methods and devices is helping. The actual machinery of the gins, the methods of using it, and the factors that make for success, are being studied in an experimental gin plant and laboratory built for these purposes. Attention of the research staff has been focused principally upon those problems of great concern to the cotton grower and ginner, such as the influence on ginning (1) of seed cottons of different staple lengths, moisture contents, and seed characteristics; (2) of different methods of harvesting and different periods of picking; (3) of varying degrees of cleaning and extracting; and (4) of saw speeds, seed-roll densities, and number and design of saw teeth. Results obtained in this work are going into commercial practice with resultant economic savings.

Cotton Utilization

Efficient disposal of the cotton crop as a whole is dependent in part upon a comprehensive understanding of the techniques of utilization. Moreover, expansion of markets for cotton through the development of new uses is dependent upon adequate technological and economic information regarding the uses for cotton. The paucity of information on the technology

and economics of cotton utilization is evident in the literature of cotton marketing.

For example, the effect of long-draft spinning upon the qualitative requirements of cotton mills that spin various kinds of yarn is as yet not fully understood, although cotton mills have been installing this type of machinery for about 15 years. It is known that long-draft spinning is probably the most important technical development that has taken place in the cotton-textile industry during recent years, from the standpoint of cost reduction. A complete understanding of the effect of changes in staple length and grade, upon the cost and quality of finished cotton goods, is lacking, from both a technological and an economic point of view. Such information is basic to a quality-improvement program for American cotton and more must be known about qualitative requirements in the future.

More is known about quantitative requirements for cotton than about qualitative requirements. Techniques for obtaining information regarding the amount of cotton used for various purposes have been developed. This information has been helpful in developing techniques designed to widen the uses and thus the markets for cotton. The main objective of this work is to develop cotton materials that are better suited for various uses than the products now in use and thus increase the uses for cotton. Cognizance is taken of the fact that wool and other textile materials are better suited than cotton products in certain uses and that unless a more suitable or a cheaper cotton material of equal quality is available cotton will not be used in these instances. It would be uneconomical and socially undesirable to use cotton in such instances.

Included among the new materials developed was a cotton airplane fabric, during the World War. More recently the United States Department of Agriculture has designed and directed the manufacture of open-mesh cotton bags for packaging fruits, nuts, and similar products. A cotton material that is suitable for bagging for cotton and that would be economical in some years, if net-weight trading—which seems economically desirable and probably will eventually be generally practiced—were adopted, has been developed. The most recent development is a cotton fabric for reenforcing bituminous-surfaced roads, which may make possible the maintenance of improved country roads at a lower cost.

The passage of the Federal Warehouse Act of 1916 marked the beginning of vast improvements and modernization of warehouses, equipment, and techniques. The warehouse receipt has become a universally accepted collateral for loans. Insurance rates have been reduced. Accounting methods have been improved. Mechanical means for cheaper and more efficient handling of cotton have been developed. Weather damage to cotton has been reduced. Virtually all of these improved techniques have resulted in lower marketing costs for cotton in transit from the farm to the ultimate users.

No discussion of technological progress in cotton marketing and distribution would be complete without some mention of cottonseed. In a little over 60 years cottonseed has been converted from a very troublesome waste into one of the major cash crops of the South. The growth of the commercial utilization of cottonseed has resulted principally from the technological improvements ranging from the discovery, in 1879, that cottonseed oil could be purified for human consumption to the promulgation of official standards for grading, sampling, and analyzing of cottonseed sold for crushing by the United States Department of Agriculture in 1932. These standards are widely used and it seems probable that in the future much of the technical progress in the marketing and distribution of cottonseed will come through improvements in the extent and techniques of grading. These should result in stabilizing marketing practices, narrowing the price spread between producer and consumer, and payment to individual farmers on the basis of the quality of their product.

Lower Costs and Higher Living Standards

Most of the work that the United States Department of Agriculture has undertaken in connection with cotton marketing has been aimed directly or indirectly at lowering the price spread between producer and consumer. Both the cotton farmer and the cotton consumer have benefited and probably will benefit from most of this work. Not all of it has yielded immediate tangible results. Ultimately the savings from a more efficient marketing system will be reflected in part in higher returns to growers and in part in lower costs to consumers. The standard of living of people generally should thus be raised. Our techniques for measuring the extent to which each group benefits have often lagged behind tangible advances in marketing techniques, such as the promulgation and practical use of standards for the grade and staple of cotton.

Crisis Met With a Social Invention

The crisis in cotton marketing brought about by declining world prices for cotton and excessive stocks and other developments associated with the economic depression was met by techniques revolutionary in character. The story of the Agricultural Adjustment program in all of its ramifications and endeavors as related to cotton is a chapter in economic and agricultural history that is yet to be written in its entirety. The Triple A is a social mechanism that may be subject to

as much improvement as was the first cotton gin. It or some other means for securing more equitable incomes for cotton farmers and conserving the agricultural resources of the South was long overdue. Social inventions such as this have been implemented by techniques previously developed through marketing research and it is probable that the continuation of the Triple A may facilitate the use of other techniques now in the process of development by market research workers in the United States Department of Agriculture and elsewhere.

Looking ahead along the tangled and complex paths through which our farm products are marketed, whether for food or for textiles, we see the problem of letting in the light, of straightening out and clearing channels, as receiving chief attention. Effort will be designed to help both farmers and consumers. The two aims are not incompatible. As our marketing program deals with the materials for the food and clothing of this and other nations, perhaps in no other line of work is it more necessary that the technician and the social inventor work hand in hand.

X. INDUSTRIAL UTILIZATION OF FARM PRODUCTS[12]

There are a number of possibilities for the extension of present uses of agricultural products in industry, but before these can be properly evaluated consideration must be given to present industrial trends which might have a limiting effect on such expansion.

Synthetic Products

Acetic Acid, Acetone, Ethyl-Alcohol.—Acetic acid is produced by the fermentation of the natural sugar extracted from plants, and may be also made by hydrolyzing the starch or cellulose content of the plant into sugar. When sugar is fermented by yeast, ethyl alcohol and carbon dioxide gas are produced, and the alcohol can then be oxidized to acetic acid by the further fermentative action of vinegar bacteria. Acetic or other acids may also be produced directly from cellulose by employing special bacteria. The acetic acid in turn will produce acetone by suitable chemical or bacterial treatment. To produce these same compounds by chemical synthesis, lime and carbon are combined to produce calcium carbide which yields acetylene by reaction with water. Acetylene can then be converted into acetaldehyde, acetic acid, and acetone under proper catalytic conditions. At present, this process constitutes an outlet for the waste products of the carbide industry, but by expansion the fermentatively produced products might be entirely supplanted, since the cost of the synthetic product is low. Acetic acid is also produced by the destructive distillation of wood, by which process methanol (wood alcohol) and formaldehyde are also produced.

Methanol and Formaldehyde.—Methanol and formaldehyde result from the pyrolytic decomposition of any cellulosic material and therefore can also be produced from farm waste products such as oat hulls, corncobs, nutshells, and fruit pits, although at present the commercial destructive distillation products are mainly produced by wood distillation. However, methanol is also commercially synthesized by combining carbon monoxide with hydrogen gas under pressure in the presence of a catalyst. Formaldehyde is an oxidation product of methanol. Because of its low cost, the present synthetic methanol has practically driven the destructive distillation product from the market, except in certain limited fields, such as denaturation of industrial alcohol.

Ethyl, Isopropyl, Butyl, and Amyl Alcohols.—By changing the conditions of the pressure catalytic process, or by changing the kind or percentage of the raw gases used, higher alcohols may be produced, such as ethyl (or grain), isopropyl, butyl, and amyl alcohols. Such alcohols may also be produced from the olefines present in natural gas or in the distillation gases from the petroleum refining industry. Industrial plants have already functioned successfully in producing ethyl alcohol from both of these sources. Ethyl alcohol may also be produced from wood by hydrolysis of the cellulose of the wood into sugar and subsequent fermentation. Several plants have already been erected in which chipped wood is treated with mineral acids and the resulting product is either used directly as a stock food or is fermented into alcohol.

Rubber.—Commercial rubber has been produced heretofore from the sap of the rubber tree. However, not only are rubbers producible from what are now considered weed plants (golden rod, milkweed, etc.), but recently a synthetic product has been produced from acetylene gas, which is further synthesized into a product known as chloroprene rubber. Other synthetic rubberlike compounds are being made.

Resins and Plastics.—Our present civilization is making increasing use of artificial resins and plastic compositions. Resins of the bakelite type are combinations of aldehydes and phenols. Aldehydes are produced by fermentation of carbohydrates, by chemical or bacterial oxidation of alcohols, and by destructive distillation of cellulosic products. Phenols are also

[12] This section was prepared by P. Burke Jacobs, Senior Chemical Engineer, in charge Agricultural Byproducts Laboratory, Bureau of Chemistry and Soils, U. S. Department of Agriculture.

produced, to some extent, by the destructive distillation process. But phenol can also be produced from coal, and aldehyde from acetylene gas. Furfural is a special aldehyde which is being produced from the pentosan content of agricultural wastes by distillation with mineral acid. Plastics are also made from the casein recovered from skim milk, from the proteins of the soybean and other oil seeds. Other plastic resins are synthesized from urea.

Other Synthetic Products.—The substitution of artificial coal-tar dyes for indigo and other natural vegetable dyes is a classic example of modern synthetic organic chemicals displacing natural products. Synthetic processes might conceivably be used to produce fats, carbohydrates, vitamins, and hormones. Such processes are seriously foreshadowed by the results of laboratory experimentation but are not economical as yet. It seems doubtful whether sugar, starch, or complex fats suitable for food can be produced synthetically at a cost to compete with the natural products. In the case of vitamins, there is some possibility that commercial synthesis may be accomplished. Various organic drugs have been produced without resorting to plant life for the original material.

Oil paints and varnishes depend for their protective power on the formation during the drying stage of an oxidized film that is hard and somewhat resinous in character. Vegetable oils are classified as "drying" or "semidrying", depending on the rapidity or completeness with which they dry by absorption of oxygen. The relatively cheaper petroleum oils do not have this drying or oxygen-absorbing property, but with modern synthetic methods compounds have been produced from petroleum which have some drying properties.

From these examples it is evident that the supplanting of farm products by nonagricultural products, as industrial raw materials, is already well under way in certain lines. There is, too, a possibility that uncultivated agricultural products will become raw materials to compete with farm products. The use of wood waste at very low cost adversely affects the possible utilization of crop wastes.

Increasing Utilization of Farm Products

In expanding the use of agricultural surpluses in nonfood industries, certain trends are under way which may result in greatly increased consumption.

Cellulose Products.—We live in a cellulose age. Heretofore cellulose has been used mainly in the form of lumber (wood), paper, cotton, and linen. Tremendous quantities of cellulosic wastes are destroyed annually as crop byproducts, which are suitable for producing synthetic lumber, insulating board, paper, absorbent paper products, and cellulose derivatives, such as rayon, lacquer, etc. The enormous consumption of cellulose by the paper industry continues to increase. The young industries of synthetic lumber and construction insulation board have established places for themselves in our economic life. Delayed somewhat by our general economic conditions they are again demanding increasing amounts of cellulose. The world rayon output during the last 10 years has increased fivefold, and although today the production exceeds 1 billion pounds annually the increase continues. For example, the increase in the rayon production in 1935 nearly equaled the total world production 10 years ago. The rayon staple fiber production today only equals the rayon yarn production of 12 years ago, but this production increased almost threefold in 1935. Staple fiber is made into a distinctive separate textile which is becoming very popular. Rayon staple fiber, cellulose plastics, and some of the lacquers are yearly demanding increasingly large amounts of industrial alpha-cellulose. The shoe industry through new innovations in its processes is demanding large amounts in special grades of industrial cellulose. In producing 1 ton of cane sugar, about 1 ton of sugarcane bagasse is also produced. This waste has until recent years been used as a fuel in the sugar factories. Now the fiber board industry uses large amounts of this waste, as well as some cornstalks and straw. It is easily possible to go far beyond the present styles of boards produced and enter other fields of building material not at present competitively attacked. The use of wood waste for producing fiberboard can be supplanted by the use of cornstalks or straw, should competitive prices permit. A large variety of pressed products can be produced from such materials as straw, cornstalks, and sorghum cane waste, and several plants are already in operation. By further refining, many grades of paper can also be produced from these materials, and by still further chemical treatment it is possible to make cellulose derivatives from which textiles, plastics, lacquers, films, cements, and explosives may be produced. More than a hundred million tons of cellulosic material are produced and wasted annually as byproducts of our grain crops. Seed flax straw, for instance, a byproduct of the linseed-oil industry now largely wasted, can be processed to yield paper or fiber for textiles.

By processing certain vegetable oils, such as linseed, soybean, and tung oils, many new industrial products having special properties might be evolved. The new synthetic casein wool fiber ("lanital") made in Italy is based on the casein obtainable from that Nation's supply of skim milk. Soybean protein might possibly be substituted for the skim milk casein. A pound of coagulated skim milk is needed for a pound of this yarn. Present production capacity is stated to be 11,000 pounds a day. Comparable production in

this country would consume substantial amounts of soybean and skim milk casein. New oils can be recovered from grape and tomato seeds, nut shells, and fruit pits. By hydrolyzing cellulose certain adhesives are theoretically possible. The present production of furfural from oat hulls might be greatly expanded and other crop wastes might be used as a source of supply. At present, furfural has been used for decolorizing wood rosin, for producing plastics, and for treating lubricating oils used in internal combustion engines. Furfural, however, forms the basis for a number of synthetic chemical reactions whereby dyes, perfumes, and other compounds are evolved.

Furfural exhibits antiknock and antioxidant properties when added to motor gasoline and might be used alone as a motor fuel. It has been used to stabilize petroleum oils and as an ingredient of embalming fluids. The principal objection to its use in many lines of work lies in the fact that its compounds are dark colored. If this coloration difficulty could be obviated a large field of uses would be opened. It is from the petroleum industry that the new increase in the demand for furfural has come. It has proved very successful in the purification of petroleum oils and the needs of this giant industry are such that the demand for this compound has been materially increased.

The use of ground materials such as cobs and nut shells to produce substitutes for wood flour may be greatly expanded. Large volumes of wood flour are used in the explosive industry as a diluent and in the molded plastic industry as a filler. Much of this wood flour is imported and sells at a price that invites competition from processors of cellulosic farm waste. Experimental work has failed to show that flour from these wastes will not meet the specifications upon which wood flour is purchased. Incidental to the use of the cortex fiber of cornstalks for paper or other purposes, pith may be obtained as a byproduct which will find use as an insulation material and absorbent for nitroglycerine for the manufacture of dynamite. The possible future growing of the Jerusalem artichoke for the production of a sugar known as levulose, from the tubers, would probably involve necessarily the utilization of the tops for paper or board manufacture and would result in the production of a considerable quantity of certain crop byproduct pith having unusual properties.

By hydrolizing cellulose wastes with acid and fermenting with special micro-organisms, alcohols, organic acids, and useful gases are obtainable which may find application in industry. By destructive distillation of certain crop by-products, acetic acid, methanol, tars, and activated carbons can be produced. Such activated carbons may be used for decolorizing oils, deodorizing, purifying of municipal water supplies, recovery of vaporized organic solvents, etc. From the tars, creosols and oils having marked insecticidal properties can be recovered. From pecan shells a tanning extract might be recovered, and ground corn cobs might possibly be used to replace spent tan bark in the manufacture of white lead. Cobs, hulls, and other crop wastes, as well as the charcoal resulting from their destructive distillation, may be pressed to form fuel briquettes for farm use. Cellulose pulp might be pressed into shapes such as window frames and chair seats, replacing other industrial materials, or used in conjunction with other materials to secure lightness and porosity. Vegetable oils may be treated to increase their lubricating value for special purposes, especially in internal combustion engines.

By fermentation, alcohols or special compounds may be evolved from pulp-mill wastes or from the byproducts of the constarch industry, from which also lactic and acetic acids are possible resulting products. Oxalic acid can be produced from corn cobs or oat hulls. Xylose, a nonfood sugar of unknown value, can be produced from cottonseed hulls or similar wastes. Insulating material might be produced from feathers or, by suitable treatment, feathers possibly could be converted into artificial silk. Cellulose fibers may be substituted for rock wool or other mineral insulation. The further use of casein for new resins and plastics is possible. In addition, the incidental recovery of lignin in the processing of cellulosic wastes may result in new industrial uses of this product, which is now entirely wasted, and yet which constitutes 30 to 40 percent of the original material. From the alcohols and organic acids derived from agricultural products various solvent esters may be produced.

Alcohol may be used as fuel for automobile engines to compensate for a diminishing petroleum supply. This would provide an enormous outlet for farm crops and byproducts high in fermentable matter. On the basis of present crop production the normal surplus of corn would supply only a small quantity of the alcohol required for even a 10-percent blend with gasoline. At present, alcohol costs approximately five times as much as gasoline, and even with an increasing gasoline price the cost of alcohol must be further reduced, entailing the use of cheaper raw material as well as new economies in methods of production.

Rubber is almost entirely imported. The production of satisfactory rubbers from domestic plants which could be grown as new annual crops might affect the agricultural situation. There is also some possibility of synthesizing rubber from the forest product turpentine.

Naval stores, so-called, are usually not considered to be farm products, but their production is a factor in

certain southern rural areas. Heretofore, the main use of turpentine has been as a paint and varnish thinner, but with the increased use of petroleum thinners and the decided swing toward lacquers in recent years the turpentine market has suffered. Turpentine is an excellent solvent and it is probably the cheapest available essential oil. It has certain peculiar chemical properties which make it eminently suitable for certain uses. One can visualize a future development in the naval-stores industry whereby the commercial mixture now known as turpentine will be fractionated into its components such as alpha- and beta-pinene, limonene, and dipentene, which will find enlarged markets for solvent or other purposes. Furfural is now used in decolorizing the rosin resulting as a byproduct from the solvent-extracted wood-turpentine industry. This furfural is largely recovered, but some possible new adaptations possibly in combination with turpentine constituents, might be visualized.

There is a possibility of using either agricultural or nonagricultural raw materials, interchangeably for producing the same or similar derived products. Any prognostications are subject to the prevailing economic situation, to the relative obtaining prices of raw and finished materials, and to the existence of other competing raw materials.

XI. TRENDS IN FORESTRY[13]

Federal properties are but a part of all those wild lands which constitute more than 60 percent of the area of the continental United States. This huge empire is sparsely populated. Though much of it has been exploited and abused, it still contains vast forests to which we must look for present and future timber needs. It grows forage, harbors much of our remaining wildlife, furnishes outdoor recreation for millions of people each year; and its forest and other cover help protect little waters which later flow through industrial centers and fertile fields. So existing and potential values of this wild-land empire are enormous.

Applied to this huge area, and with the impetus given by the current interest, many technologies being developed in regard to the national forests promise to have a profound effect upon other public and private forests and upon the social structure of the entire Nation.

Forest Influences

Nature created forests, spacing them strategically on watersheds throughout the country, where they served in part as huge sponges for absorbing rainfall and maintaining the soil and water supply. Similarly, nature clothed mountain slopes and hillsides, valleys, and plains with grass and other herbaceous vegetation which helped percolate precipitation into the soil. But man has disturbed nature's balance.

Without trees, shrubs, grass, and allied cover as deterrents, precipitation forms ever-growing little waters; rivers rush to the sea from their sources on exploited watersheds. This action, plus that of winds, leaves soil erosion and calamity behind. Specialists tell us that the dust storm of May 1934 swept 300 million tons of fertile topsoil off the great wheat plains; that 400 million tons of remaining material are washed annually into the Gulf of Mexico by the Mississippi; that generally water and wind erosion together each year remove beyond use 3 billion tons of soil.

Numerous measurements and tests are being made throughout the United States. Immense amounts of data have been collected and analyzed. Values of forest, range, and other vegetative cover in flood prevention and soil absorptivity have been established.

But technologies are as yet in the preliminary stages. They must be further developed and refined, and applied Nation-wide. For social significances of preventing floods and erosion and regulating streamflow by means of vegetative control are broad and far reaching. They impinge upon agriculture and industry alike. The present and future of communities such as those of southern California are directly linked with proper water conservation and use.

Technologies of Multiple Use

There are several methods by which the national forests and their many resources, including water, forage, wildlife, and recreation as well as forests, might be conserved through management. One is by locking them up—conservation through abstention from use. Another is by permitting one planned use or type of use, in effect locking up most of their resources. This is the tendency on wild lands in private ownership. Under either of these two methods most of our renewable resources and the lands themselves must inevitably be under utilized. Yet nature's gifts are the basis of all economic life.

A third method of conservation is to provide such management as will assure the greatest social and economic good to the largest number of people in the long run. Called multiple-use, this socio-economic principle requires development, refinement, and application of many management techniques to the land, to every one of its resources, and to all the services that both may render to man. Above all, it requires plan-

[13] This section was adopted from material prepared by F. A. Silcox, Chief of Forest Service, United States Department of Agriculture.

ning and coordination of techniques, with vision and forethought for the needs of the future.

Invention of new socio-technical theories and practices has made possible the demonstration on the national forests of multiple-use land and resource management. Because of multiple-use of such land the net total yield of human, economic, social, and aesthetic values derived from a given land area exceed those obtainable from any customary single use. The resulting influence on living standards is definitely upward.

By means of these and other technologies the principle of multiple use may be extended to forest, range, and other wild lands generally, including in large measure such lands as are and may remain in private ownership.

Technologies of Producing, Managing, and Harvesting the Forest Crop

Four-fifths of our commercial forest land is in private ownership. It still furnishes 98 percent of all our forest products. With but minor exceptions, timber on it has been mined rather than cropped. For decades, fire protection was nonexistent or utterly inadequate. Immediate economic necessity, rather than scientific knowledge, still rules in the selection of species and trees cut. Through ignorance and economic pressures, little attempt has been made to leave the land productive. Forest operations have been transitory. Cut out, burn out, and get out has been the order of the day. Ghost towns, depressed agriculture, distressed social structures, have resulted. Now, when physical frontiers are gone, natural resources are limited, and many other conditions over the country have changed, these sores are difficult to heal. New ones cannot be tolerated, for the cumulative effect is very definitely felt on the social and economic structure of the Nation.

Technologies developed, refined, and applied by the Forest Service in connection with growing, harvesting, and managing the Federal forest crop, promise relief from the consequences of past practices on other wild lands. Included are technologies having to do with forest protection; silvicultural, nursery, and planting methods necessary to insure forest reproduction; selection and breeding of individual trees and tree species to increase future forest values; methods and machinery for harvesting rather than exploiting the forest crop; current forest inventories, and sustained-yield forest management.

Applied to a Great Plains area of some 70 million acres which includes more than 185,000 established farm units, some of these technologies will make of it a better place in which to live, will produce trees that grow faster, are less exacting as to soil and moisture, and will serve local needs to better advantage. And still wider application of all of them should make it possible to so manage our forest resources that—in part through a new type of forest community—it may in the future help to support with security and stability a greater share of the Nation's population.

Technologies of Forest Taxation

Reference has been made to the prominent part which private ownership must play in the development of sound forestry, and to the economic pressures which heretofore have tended to obstruct forestry and to promote destructive practices on privately owned lands. An element in these economic pressures is fear of burdensome and inappropriate taxation. Studies in forest taxation have developed a program which, if adopted by the States, will go far to remove this fear and to place forestry, so far as taxation is concerned, on a par with other forms of land use. The solution of the forest-tax problem will contribute substantially to bringing about better utilization of the forest resources which remain in private hands.

Technologies of Wood Utilization

During the past 20 years our per capita consumption of wood fell greatly, even in predepression years. Despite increases in population, so did total consumption. Investigations show that many former markets for wood have lately been unprofitable or unsatisfactory. Not because the material lacked intrinsic properties that were needed but partly because of improper preparation or unhandy forms for use, and faulty design of the commodity or the structure in which it was to be used.

Technologies with respect to wood utilization, evolved and adapted by the Forest Service point the way for wood and its products and byproducts to regain and broaden many old markets and capture new ones. Techniques in the pulp and paper industry include those having to do with utilization of new woods, modifications of mechanical and chemical pulping and bleaching processes, and application of them to woods that are cheaper and more plentiful than those heretofore used. In the construction industry are techniques having to do with usable strength data and grading rules for lumber and timber; use of chemicals to preserve wood and make it fire resistant; construction of large wooden members from small dimension stock; development of new structural units and systems adapted to large-scale production and rapid field assembly with low first cost, depreciation, and maintenance. In the chemical conversion field, technological developments include those to make wood plastic, bacterial fermentation of cellulose to acetic acid and isopropyl alcohol, and the production of wood gas and alcohols.

Application in industry and commerce of such technological developments presage things of wide

social import such as diversification of raw material for pulp, low-cost housing, and motor fuels that may successfully be used when gasoline becomes scarce or too high in price. They point to more complete utilization of wood waste (which has in the past reached 50–60 percent of the actual material grown or available on the stump), and added employment by the forest industries. They lead to conservation of our remaining forest resources.

Other Technologies Applicable to Wild-Land Resources and Services

(*a*) *To forage.*—Within the continental United States more than 334,000,000 acres of forest land are grazed by domestic livestock. In southern pine forests, forest forage is of distinct value to the rural population. In the humid East, grazing is usually detrimental to hardwood forests. In the West, where wild-land forage largely involves the national forests and the public domain, economic and social welfare is frequently dependent upon forest-land forage.

The American tendency to abuse and ruin grazing lands is historic. Overgrazing has been followed, all too often, by capture of soil by relatively worthless weeds, and erosion. This process has adversely affected enormous farm values, thus contributing to collapse of economic and social structures.

Technologies developed through research and applied administratively on the national forests, and other technologies now in process of development, promise to show the way to halting overgrazing and its inevitable consequences. Among these techniques are: Improved systems of grazing to bring about natural revegetation, obtain more stable forage production, and minimize livestock damage to timber production; development of methods and species for artificial reseeding of wild-land ranges and abandoned dry farms. Soil science, botany, range ecology, and the behavior of soils and plant and animal life under different methods of treatment are involved.

Combined into a socio-technical system of control, such techniques promise to bring huge benefits if they are extended to our seven hundred-odd million acres of range lands. For this resource might then contribute far more than it ever has done to the support of successful homes and prosperous communities.

(*b*) *To wildlife.*—A substantial part of the remaining wildlife in the United States, valuable for food, fur, and hunting, or for aesthetic purposes, finds its home on forest, range, and other wild lands. Wildlife directly interests more than 13,000,000 people who hunt and fish each year. It helps support many more and adds to the happiness of millions who are eager to catch a glimpse of wildlife in its home environments. This subject is dealt with in the section which follows, entitled "Technology and Wildlife."

What the Future Holds for Forestry

Primarily it holds an inescapable obligation to determine which lands of the Nation will render their highest and most permanent social and economic service through forest use, and to apply to such lands the best principles of management that can be evolved by human intelligence through the processes of science and research. It holds the need to substitute for crude processes of utilization new principles and methods through which the potentialities for human service, inherent in forests most completely, can be realized. It holds for the wood technologist, the chemist, and the silviculturist boundless opportunity for the development of new technologies contributing to human progress and welfare.

The potentialities of forests and their products have been only partially and vaguely determined. Their latent values as sources of both mechanical and human energy largely remain to be developed. Under skilled technical direction of the scientist they may be employed to supply a wide array of human needs in ways superior to those by which such needs now are met, and thereby develop a new outlet for labor. Wood as a source of mechanical energy has now passed beyond the field of experimentation. It is our greatest source of cellulose. Its preeminence as a source of numerous elements or substances basic to a wide array of useful commodities already is established.

Restoration of the United States to a condition of natural equilibrium is vital to its security and permanence. That requires the restoration of forests to much of the land from which they unwisely have been removed. To that end, ways must be devised whereby the products of forests may replace our nonrenewable natural resources. That is the field which lies ahead for the scientist and the technician.

XII. TECHNOLOGY AND WILDLIFE[14]

Few students of technology recognize the social importance of wildlife and the rapid strides which are being made in technologies affecting its preservation, development, and utilization. Publicly sponsored activity is increasing in research and management both in States and by the Federal Government. Wildlife is so closely associated with agriculture, with farms

[14] This section was prepared from information supplied by W. L. McAtee, Technical Adviser and Research Specialist, Bureau of Biological Survey, U. S. Department of Agriculture, and other sources.

and forests, that this technology deserves consideration with other fields more familiarly associated with the term "agricultural technology."

Because of long-continued and thoughtless exploitation, wildlife was greatly reduced. On areas where opportunities have been provided for demonstrating wildlife techniques, however, many striking instances of restoration have resulted.

Restoration has social significance not merely in satisfaction to sportsmen. It has meant a contribution to returning the balance of nature, to increasing the number of persons who depend upon wildlife, directly and indirectly, as a source of income; it has contributed to the food supply and to aesthetic satisfactions. Wildlife management is a field of knowledge and activity which promises to advance far in the next two generations.

Instances of restoration, reversing the trend of wildlife depletion, has been accomplished by development and application of techniques having to do with production and use of forage, as well as bio-ecological methods involving technical determination of food, feeding, and other wildlife habits.

Among techniques connected with wildlife generally those of classifying animals, working out influences of environment, and tracing their movements were prominent in early techniques of the Biological Survey and are still continued as basic research. Identification is the key to all that is known of relationships, distribution, and habits, and it enables the wildlife technician to shape his practice in the light of knowledge that all investigators, everywhere, have accumulated.

Millions of records from all sources have been assembled providing a satisfactory basis for generalizations in regard to the migration work. The technique of bird banding has been adopted, improved, and extended. Through it the movements of individual birds are traced, thus making possible more accurate definition of migration routes, general bird flyways, and winter and summer ranges. The scientific data bearing on the ranges and movements of birds are indispensable to proper conduct of wildlife management problems involving more than a single State. They have resulted in the annual promulgation of regulations protecting birds migrating between the United States and Canada, and the establishment of a system of migratory bird refuges giving adequate protection to wildfowl on the breeding and wintering grounds, and throughout the major flyways of the United States.

The technique of food habits research involves laboratory analyses of all sorts as well as field investigations of feeding habits and of the utilization of food supplies.

From the technique of research into their food habits have developed a number of other techniques for the improvement of environment, and for the encouragement of desirable and the control of undesirable species. Originally developed to throw light on economic values in relation to agriculture, horticulture, and forestry, this work soon responded to the needs of wildlife management.

Efforts to increase the more valuable kinds of wildlife developed in one direction into recommendations as to choice of kinds, care of propagating material, and as to where, when, and how to set out valuable wild-duck food plants. Plants affording refuge shelter and nesting cover were included and the technique became one of general improvement of the environment of wild fowl. These recommendations were acted upon extensively through a long series of years and resulted in great improvement of some properties (up to a tenfold increase by the financial scale), and are now serving as the basis of development and improvement of the vast new system of Federal migratory bird refuges (over 100 totaling more than 1,600,000 acres). Recommendations as to the value of marsh and aquatic plants and as to methods of propagating them have been of value also to muskrat farming.

XIII. THE DAIRY INDUSTRY[15]

Advances of the dairy industry result from efforts in three main directions: Improvement of quality of dairy products, efficient and economical production of milk, and the efficient distribution and consumption of milk and products manufactured mainly from milk. The last may include the development of new products as well as the extension of the use of those already developed. The aim in these fields of effort is to promote the use of greater quantities of dairy products. This can be accomplished most readily by decreasing the cost of milk products to consumers and by improving quality. For, although the nutritive and salutary advantages of milk and its derivatives in the diet are of great social importance, these reasons for increasing consumption are not so readily accepted by consumers as the most immediate and urgent arguments of greater saving of expense and of greater desirability of the product.

Decrease of retail prices cannot reasonably be made arbitrarily by cutting the dairy farmer's income, but must be brought about through greater efficiency and economy in production and distribution of dairy

[15] This section was prepared by E. O. Whittier, Senior Chemist, Bureau of Dairy Industry, U. S. Department of Agriculture

products. Research and dissemination of the results of research are the means whereby quality improvement is being effected.

Breeding

Increase in our knowledge of the laws of breeding of dairy cattle and the wider dissemination of that knowledge are capable of increasing the average quantity of milk produced per cow, and of increasing the average quantity of fat per cow, not only through the increased quantity of milk, but possibly also through the increased percentage of fat. At present, fat is the most valuable constituent of milk from the dollar standpoint. It may seem to some observers that the possibility in maximum milk and fat yield per cow has advanced close to its limit, but much certainly remains to be done in carrying the available knowledge of better breeding to the dairy farmer and in inducing him to adopt its principles. As these principles are adopted, the overhead of labor and maintenance costs per unit of product decreases and a lowering of price to the consumer becomes possible.

Feeding

The cow is frequently spoken of as a machine for the conversion of feed into milk. The comparison is valid, not only for the function of the animal, but also for the relationship between the types of raw material fed and the quantity and quality of the finished product.

There is a tendency to change from the older rations of hay and grain for dairy cows to rations containing greater proportions of roughage—or even roughage alone—in the form of pasturage, well-cured hay, and silage. This change has recently been given impetus by methods of ensiling grasses, which contain no fermentable sugar, by the addition of molasses, whey, or other source of fermentable sugar or of mineral acid; and by a method of artificially drying of roughage so as to retain practically all of the nutritive constituents that were present in the green material.

Not only is there a direct economy in this scheme of feeding, but the quantity of vitamin A in the ration is thereby considerably augmented. Occasionally an extreme deficiency of vitamin A in the diet of the cow causes calves to be born blind or dead. Furthermore, the vitamin A supply of the cow is reflected in the vitamin A content of the cream and butter derived from the cow, which vitally affects human nutrition. This will be mentioned in that connection later.

The growing of more roughages and legumes, and of less grain, is of vital importance to the Nation in preventing soil erosion and in increasing and retaining soil fertility. Since from 70 to 90 percent of the grains grown are used for livestock feeding, an extension of the feeding of roughage would cause a redistribution of livestock farming. A smaller number of cattle would be kept in the vicinity of large cities, where large quantities of purchased feeds are fed, and those farmers who now specialize in raising grain would tend to raise livestock.

Experiments have shown that cows will produce about 70 percent as much milk on a ration consisting entirely of roughage of good quality as they will on a full-grain ration. Statistics indicate that the full-grain ration represents the average dairy feed of this country. If all our dairy cows were shifted from a full-grain ration to a roughage ration, it would take 50 percent more cows to produce the same quantity of milk as is produced at present.

The social change in many rural areas would be great, since the entire method of cropping would be changed. Instead of the routine of plowing, seeding, cultivating, and threshing each year, most of the land would be laid to perennial grasses and legumes that would be cut frequently at early stages of growth in order to obtain the maximum nutritive values. This frequent cutting would help in the control of weeds. Irrigation would become more common in those regions where necessary in order to maintain a more nearly constant rate of growth of herbage during the growing season. The appearance of the countryside would be vastly improved, since gullies, eroded areas, and weed patches would be largely eliminated and the fields would come to resemble lawns.

Delivery of Dairy Products

The question of changing methods and time of delivery of family milk supplies and the forms in which milk is offered becomes increasingly important socially. At present in most cities the milkman starts on his rounds at a very early hour in order that fresh milk and cream may be delivered in time for his customers' breakfasts. This schedule makes his life abnormal and irritates that great number of light sleepers. For each quart, or 2 pounds of milk on his truck, the milkman carries 2.6 pounds of bottle and bottle case, and for the smaller units of cream the proportion of dead load is still greater. Only between one-third and one-half the load on an outgoing truck consists of milk. The cost of such a method of retail delivery averages about 4 cents per quart. In summer, the milk is sometimes warm when the customer takes it into the house; in winter, it is frequently frozen. Overlapping of routes is a large question.

Researches in refrigeration, in container technology, and in the chemistry and bacteriology of dairy products have shown ways out of some of these awkward conditions. The greater refinements in sanitation on the farm and in the dairy, the development of more

effective refrigeration for the farm, for tank cars and trucks, for the dairy plant and for the home, and the attainment of greater speeds of transportation, have all contributed to make retail milk more palatable, much safer, and much less rapidly perishable than it was only a few years ago. It may now be kept for several days in the home refrigerator in excellent condition, instead of souring within a few hours. This points toward delivery of milk at times more convenient for both delivery man and customer. Daylight deliveries are already made in a few cities.

When the single-trip lightweight containers already in limited use in a few cities for milk sold from stores become somewhat less expensive and sufficiently durable to be used more than once, they will be used in retail deliveries. Other developments that tend to increase the salable proportion of the milk truck's load are the popularizing of milk powder and of frozen concentrated milk. Research will make it possible to accomplish sterilization with less or no cooked taste imparted to the milk. This will lead to greater use of evaporated milk in place of fresh milk.

Cheese

Cheese is a relatively neglected item of diet in the United States, the per-capita consumption in Europe being from two to three times greater than here. Consumption of large quantities of meat of itself need not affect cheese consumption unfavorably, for in England the consumption of both meat and cheese is high. Higher quality and somewhat lower prices appear to be the feasible means of increasing cheese consumption. Increased domestic production of high-grade cheeses of considerable variety should decrease prices noticeably. If part or all of the 60,000,000 pounds of relatively high-priced cheeses of foreign types now imported were manufactured in this country, the producer of cheese milk would benefit by higher milk prices, both because of the increased volume of milk required and because of the leveling-up effect of the greater market value of the foreign-type cheeses. Use of pasteurized milk in cheese making is likely to bring the South more extensively into this industry, thereby giving serious competition to the cheese makers of the northern-producing areas, such as Wisconsin, New York, and Ohio.

The development of domestic processed cheese and cheese spreads has definitely increased the domestic consumption of cheese. Each cheese can now be marketed economically in the warmer sections where formerly, because only large units were available, there was a large proportion of waste from drying and molding in retail stores. The current development of ripening and marketing Cheddar cheese in cans will stimulate cheese consumption, as will any other factor that improves the quality of cheese as received by consumers.

Previous to the World War, cottage cheese was made and used almost exclusively on the farms. As a result of efforts to popularize its wider use, it is being manufactured in city dairies from surplus milk and is used in ever-increasing quantities by our city population.

Butter

Within recent years there has been a marked increase in the popularity of sweet-cream butter. The slowly increasing manufacture of this butter has already had the effect in certain dairy areas of decreasing or abolishing the separation of cream on the farm and of requiring dairy transportation of greater frequency and greater volume.

A definite preference among consumers for a yellow butter has caused the rather general addition of artificial coloring matter, a practice that has legal protection. The recent discovery that the natural yellow color of butter is a good approximate index to its vitamin A potency seems to point logically to a reversed legislative attitude that will insist eventually on having artificially colored butter so marked on its container. The recent tendency for consumer preference for lighter-colored butter is likely to subside as the knowledge of the relationship between natural color and vitamin A potency becomes more widespread. This subject is highly important socially from the standpoint of public health.

Ice Cream

The development of the commercial ice-cream business to a position of importance in the United States has taken place mostly in the last 25 years. Production has more than tripled in that time. Within the last 5 years the increasing use of electric and gas refrigerators in the home and the greater availability of carbon-dioxide ice have shifted the place of consumption of much of the ice cream from the candy and drug stores to the home. Use of packages shaped to fit easily into the freezing compartments of refrigerators will probably accelerate this shift. The heralded use of the home refrigerator for the actual freezing of ice cream has not yet developed to appreciable extent, apparently because of the lack of a stirring device to whip in air and prevent formation of large ice crystals during freezing. Freezing units with agitators are now available for refrigerators, and ice-cream mix in milk bottles can be bought in some cities. Both developments aim to shift a portion of ice-cream making from the factory to the home, incidentally increasing the quantity of ice cream consumed.

Byproducts

One highly intriguing method of reducing the cost of dairy products to the consumer for the purpose of increasing consumption is that of shifting a portion of the total costs of production to valuable byproducts of skim milk and whey. Skim milk contains approximately 2.5 percent casein and nearly 5 percent milk sugar; whey contains 5 percent milk sugar, 0.75 percent protein, and 0.75 percent salts. About 40,000,000 pounds of casein are used industrially per year in this country, most of it in the paper industry. The recent commercial development in Italy of Lanital, a textile yarn from casein, is too new for valid predictions to be made of its effect on our dairy or textile industries.

The 5 percent of milk sugar in whey continues to be a problem in economic utilization. Though valuable nutritionally, it is expensive to isolate and refine in the small quantities at present in demand. As a raw material for fermentation to organic acids, milk sugar has possibilities that are already materializing in one plant built especially for carrying out the fermentation to lactic acid. It seems logical that dried whey should be used as food, since it consists chiefly of sugar, protein, and nutritionally valuable salts. It is now used to some extent in feeds for poultry and swine, such use nearly doubling the net income from whey over what would be realized from it without drying.

A beneficial effect on quality, and consequently consumption, of butter will result from the more extensive and profitable utilization of byproducts. The farmer, instead of delivering infrequently a comparatively low-grade hand-separated cream to the dairy, will deliver with greater frequency sweet whole milk, which, by factory handling, will yield a better grade cream and a higher score butter.

XIV. COTTON PICKERS[16]

No, you dare not make war on cotton. No power on earth dares to make war upon it. Cotton is king!

(Hon. J. H. Hammond, in a speech delivered before the United States Senate, March 4, 1858.)

Cotton, perhaps more than any other important crop, has resisted the general trend of technology in agriculture. There have been advances, of course, over the primitive methods employed a century ago, particularly in breaking the soil, distributing fertilizer where fertilizer is used, and in seeding and cultivating. But two of the major operations, chopping and picking, are still with but few exceptions performed by hand throughout the Cotton Belt.

The reasons, superficially, are obvious. First, the very nature of these operations—requiring, as they do, the exercise of a selective judgment not easily transferred to machinery—offers a considerable obstacle to mechanization. Second, labor throughout the South in normal times is plentiful and cheap—conditions which tend to be perpetuated by the cotton economy, and there is no great incentive to save labor time by transferring to machinery work otherwise performed by hand unless the labor saved, in terms of money costs, more than offsets the cost of the machinery.

In fairness to inventors, however, it cannot be said that they have not tried to solve the picking problem. For generations they have worked to transfer to tireless machines the work now performed by human hands. And although the picker has only recently come to wide public attention, the records of the United States Patent Office reveal a startling list of patents granted on cotton harvesting devices of varying description and merit. The first patent was issued in 1850. By 1864 there were 12. Since 1865, patents for pickers or other cotton harvesting devices, including strippers, have been granted every year except 1899, and the total number granted now exceeds 900. But even so, the cotton crop is still largely gathered by hand just as it was a hundred years ago.

Tempered by so long a record of costly experiment and failure, most people have grown callous to the ever-recurring rumor that a practicable mechanical cotton picker is at last a reality. Today the rumor is more persistent than ever before.[17]

Even though King Cotton be regarded as something of a despot, exultation at this prospect of emancipating millions of his subjects is not unmixed with grave skepticism and misgivings. There is skepticism because the tidings have often been shouted before, and found false; there are misgivings because, if they are not false, there is reason to cringe before the possible consequences. Reassurance is wanted that a machine capable of picking in 1 day as much cotton as an experienced hand can pick in a month will be a blessing, not a curse, to mankind. The legendary Frankenstein monster turned upon his inventors and destroyed them. The victims had failed to make adequate preparations for the control of their creation. It is not too early, therefore, to look into some of

[16] This section was prepared by Roman L. Horne, of the Agricultural Adjustment Administration.

[17] See Oliver Carlson, The Revolution in Cotton, The American Mercury 34 (134), 129–136, February 1935; Oliver Carlson, The South Faces Disaster, The American Mercury, 37 (145), 1–8, January 1936; William and Kathryn Cordell, The Cotton Picker—Friend or Frankenstein? Common Sense 5 (6), 18–21, June 1936; W. Carroll Munro, King Cotton's Stepchildren, Current History 44 (3), 66–70, June 1936; Victor Weybright, Two Men and Their Machine, Survey Graphic 25 (7), 432–433, July 1936.

the problems that would be raised if this dream of a century, a successful mechanical cotton picker should come true.

Cotton's Rise to World Power and Fame

Once before cotton was the spearhead of cataclysmic change—of the revolution which removed production for the market from the home to the factory and added an era to the economic organization of civilized man. It is more than idle fancy to suppose that cotton may again play a significant part in fundamental economic and social rearrangement.

Although cotton from planting to harvest has largely defied mechanization, cotton as a raw material in the fabrication of textiles played a dominant role a few generations ago in the series of convulsive changes—technological, economic, and social—known as the industrial revolution. A brief review of these changes will help to fix in better perspective the position and importance of the cotton crop in the United States today, and perhaps throw light on the possible effects of a mechanical picker.

Until the eighteenth century cotton was virtually a novelty even in England. It was a product of foreign soils, India and the West Indies, and as such was more amenable to technological change than were raw materials going into the long-established linen and woolen industries. From the invention of Kay's flying shuttle in 1733, which practically doubled the weaver's output of cloth, to the invention of Compton's "mule" in 1779, which increased the spinners' output of yarn a thousandfold, technological improvements went forward in every department of textile manufacture. Until the latter part of the eighteenth century both the loom and the spinning wheel, however, were still hand operated, with improvements first in weaving and then in spinning disturbing the balance of the production process. It remained for Dr. Edmund Cartwright, in 1785, to perfect the power loom which drove weaving from the family fireside to the site of power—first water and later steam—and paved the way for the modern factory system.

It must not be supposed, however, that modern industrial capitalism was ushered in without challenge. There was resistance then, as now, to machinery which saved a man's back at the expense of his job. John Kay, his home razed by disgruntled workers, was forced to flee the country. Hargreaves, the inventor of the spinning jenny (1770), fared badly at the hands of his neighbors and was forced to move to a distant village to carry on his work. Compton sought seclusion in an attic in a desperate attempt to foil a suspicious and threatening mob. But however distressing the temporary maladjustments which resulted from these advances in technology, the material well-being of the average man in the long run was immeasurably improved.

By 1790 the revolutionary advances in cotton textile manufacture had shifted the immediate emphasis from technology in fabrication to the more pressing problem of relieving the acute shortage in raw materials. In the United States cotton cultivation was restricted to the coastal plains of South Carolina and Georgia, where the entire crop for 1791 did not exceed 2,000,000 pounds, or about 4,000 bales, as contrasted with present production ranging from 12 to 15 million bales.[18] Failure of the South to exploit the possibilities of cotton growing prior to 1790 was due to the more profitable alternative uses to which the land could be put—so long as the lint had to be separated from the seed by hand. Meanwhile British textile manufacturers had to look to other countries where hand labor was cheaper for their supplies of raw cotton. This obstacle was removed once and for all by the invention of the cotton gin in 1793, an event of major importance in the birth of a new industrial order. Cotton culture spread north to the "frost line", and south and west under the banner of slave-holders prior to the Civil War. In 1790 there were only 677,897 slaves in the entire country. By 1860 there were 3,933,760 with only a few hundred scattered north of Mason and Dixon's line.

Meanwhile, advances in technology, both in agriculture and in manufacturing, led to a reduction in the proportion of income which the average man had to spend for food and textiles, thus leaving a larger proportion to be spent on other necessities and on luxuries.

The Cotton Belt

The Cotton Belt, extending south and west from the southeastern tip of Virginia, is one of the most highly specialized agricultural regions in the world. On the north the Cotton Belt is bounded by the "frost line", which dips irregularly southwest as it crosses the higher altitudes, marking the upper limit of the 200-day frost-free season, and an average summer temperature ranging around 77° F. On the south it is bounded by a subtropical border beginning in the Carolinas and following the coast line, taking in the greater part of Florida and extending west around the Gulf, where excessive rainfall in early autumn would interfere with the picking season. Approximately 1,600 miles long and from 125 to 500 miles in width, the Cotton Belt comprises about one-sixth of the area of continental United States. Here, on 3 percent

[18] M. B. Hammond, The Cotton Industry: An Essay in American Economic History. Part I. The Cotton Culture and the Cotton Trade. Publications of the American Economic Association, new series, no. I, p. 21, 1897

of the earth's land surface, nearly 60 percent of the world's cotton was produced in the decade of the twenties. Seventy-five years ago, when Senator Hammond delivered his impassioned speech arraigning King Cotton against the world, the South was probably producing 90 percent of the world's cotton supply.

The population of the Cotton Belt proper in 1930 was approximately 21½ millions, one-half of which—or about 10¾ millions—was classed as belonging to the rural farm group. The other half was about equally divided between urban and nonfarm rural groups. Of the total, 30 percent, or about 6½ millions, are Negroes, more than half of whom live on farms. And while Negroes constitute only about 35 percent of the rural farm population for the Cotton Belt as a whole, in two States—South Carolina and Mississippi—Negroes on farms are slightly in excess of whites. At the western extremity of the Cotton Belt, however, Negroes constitute a very small minority of the total population. Although in the last decade there was a steady migration to the industrial North, the Negro, the mule, and the plow are still characteristic of the social and economic system which prevails in the greater part of the rural South.

The abolition of slavery first led to experiments in money-wage relationships between the plantation owner and the freed Negro. But the Negro's training generally had not made him a thrifty and long-calculating individual. He was inclined to work until he got paid, and then, regardless of the season, was likely to set forth to enjoy his new freedom until funds ran out. What was the meaning of freedom if he still had to work all the time? The landlord could get no satisfaction by suing for nonperformance of contracts.

A system evolved which gave the freedmen a sustained interest in the crop from beginning to end, and at the same time left active management in the hands of the landlord or his manager. The Negroes, for the most part, were penniless as well as illiterate and improvident, with limited opportunities for improvement. As they did not have the capital to set up as full-fledged tenants, they gradually dropped into one of the several stages of tenancy distinguished by the more or less complete dependency of the tenant upon the landlord not only for seed, livestock, and tools but also for the bare necessities of food, shelter, and clothing. As the decades rolled by the small one-mule farmer, whether white or Negro, frequently was forced to surrender his ownership status for something easier at the moment, but definitely lower in the social and economic scale. In 1880, for example, 38 percent of the farmers in Texas were tenants, as contrasted with 57 percent in 1935. In the same period tenancy in Mississippi increased from 44 to 70 percent, in Alabama from 47 to 64 percent.

According to the accompanying table, 58.4 percent of all farmers in the Cotton Belt are tenants. Of the total, whites outnumber Negroes by more than a quarter of a million, and the trend over the past decade has been toward an increase in the proportion of white to Negro tenancy.

Tenant farmers—Percentage of all farmers, 1880–1935 [1]

	United States	Cotton Belt		United States	Cotton Belt
1880	25.6	40.0	1930	42.4	61.3
1900	35.3	52.1	1935	42.1	58.4
1920	38.1	55.2			

[1] Adapted from the United States Census of Agriculture, 1935. States included in the Cotton Belt: North Carolina, South Carolina, Georgia, Alabama, Mississippi, Tennessee, Arkansas, Louisiana, Oklahoma, and Texas.

Meanwhile the center of the Cotton Belt has been shifting westward, approximately half the crop now being produced west of the Mississippi River where, especially in the uplands of Texas and Oklahoma, mechanization of cotton culture has already made considerable progress. The newer lands generally produce cotton at lower cost in terms of man- and horse-hours than that prevailing east of the Mississippi. Moreover, the larger farm units in the West make possible a more economical use of machinery and labor. For all farms reporting cotton in the four older cotton States of the Southeast—North Carolina, South Carolina, Georgia, and Alabama—only 9.3 acres on the average are devoted to cotton. In Arkansas, Oklahoma, and Texas, on the other hand, 22 acres of every farm on the average are devoted to cotton.

Mechanization of Cotton Culture

Suppose that a successful mechanical cotton picker—capable of picking five thousand pounds a day—is, or soon will be, a reality, and that it will be manufactured on a large scale and sold for approximately $1,000. What social and economic consequences might we expect?

Until mechanical cotton picking passes beyond the experimental stage limited progress can be made at mechanizing any preceding stage of the cotton crop. Tractors, gang-plows and other implements of modern agriculture have not played a more important role in the Cotton Belt because the labor of millions of workers—men, women, and children, white and Negro—is required for the picking season. Since the cheap labor is there, the cotton producer uses it as much as possible throughout the year rather than purchase expensive machinery. Furthermore, so long as a tractor, for example, cannot be used in the picking season, none

but the larger operators can afford to own one merely for turning the soil. The advent of a mechanical cotton picker, assuming its ready adoption, would make the tractor practically indispensable in the picking season. Thus the tractor's availability would be an incentive for substituting its use for that of horsepower in preparing the land for planting in the spring. It is probable that "chopping" could be further mechanized if that operation were the last requiring a considerable amount of hand labor. There are 8 to 9 million individuals in nearly 2 million tenant families in the 10 Cotton States. If mechanization proceeded rapidly without substantial change in the present cotton acreage, it has been estimated that at least one-fourth of these tenant families to three-fourths of these would no longer be needed. But any such estimate is likely to be unrealistic until the rate at which mechanization would proceed can be forecast—and this in turn awaits proof that the picker is practical and that it can be produced at low cost.

If, on the other hand, lower cost of production leads to increased consumption of cotton both at home and abroad, acreage will be expanded and many who would otherwise be unemployed will find work not only in the cotton fields but throughout the agencies engaged in handling and processing cotton. Moreover, further reduction in the cost of textiles will tend to expand consumer demands in other directions and, in turn, provide more jobs. Lower production costs offer some, but limited, assurance that we shall recapture the foreign markets once dominated by American cotton, because the same machinery would be available to other cotton-growing countries. India, Brazil, China, Argentina, and Russia are also important cotton-producing countries.

Although mechanization of cotton culture would undoubtedly hit the tenant and "cropper" farmers hardest, it would also intensify the struggle of the small farmer-owner who, with family labor, one or two mules, and rather primitive implements, has long struggled for a bare subsistence—often against harsh terms for credit both for fertilizer at the nearest village and for provisions at the crossroads store. He will be unable to buy a mechanical cotton picker and a tractor, and even if he could, its use would be uneconomical on small acreage. When cotton is 10 to 12 cents a pound the average small farmer little more than breaks even.[19] If with the introduction of a mechanical picker cotton can be produced profitably at a lower price on the larger farms, the small farmer may be overwhelmed by competition unless hand-picked cotton, because of its freedom from trash, discoloration, and roping, comes to command a material premium over machine-picked cotton.

In a restricted section of Texas an improved substitute for hand labor in picking has been in use for more than a decade. A sled or "stripper" is dragged along the rows gathering both the open and unopened bolls. In sections where this device is used, however, a large percentage of the bolls ripen at the same time. A study made a few years ago reveals that even by this crude method of gathering cotton one man with two horses and a "sled" can harvest about 4½ acres, or a little less than two bales a day at an operating cost of about $3 a bale on the basis of current dollar values, as contrasted with the cost of hand-picking ranging from $12 to $15 a bale.[20] There is, of course, a certain amount of foreign matter gathered which both increases the cost of ginning and lowers the quality of the fiber. This method of gathering the cotton crop in areas where it can be applied reduces by about three-fourths the man-hours required in picking, and, consequently the family size cotton farm can be increased in about the same proportion.[21]

Cotton Pickers

Exhibitions and tests in 1936 of cotton pickers in Texas and Mississippi have led many people to believe that the key to complete mechanization of the cotton industry is closer to a reality today than ever before. It will require several years thoroughly to test the machines on different soils, topography and varieties of cotton. But if the confidence of the inventors is justified, the picker will inevitably create new social and economic problems.

In the hundred and forty years since Eli Whitney patented the gin, millions of dollars have been spent and the inventive genius of thousands of men has been concentrated upon this search for a mechanical substitute for human fingers. If this substitute has now been found, it will deserve a place high among the inventions and discoveries which have profoundly affected the social and economic arrangements of mankind.

Pulled by a tractor, the newer type of cotton pickers straddles the row of cotton thrusting hundreds of spindles into the open bolls. The cotton, along with a considerable amount of trash, is wound about the spindles, removed mechanically, and conveyed to a container on the machine.

In exhibition tests one of these pickers is reported to have picked as much as 5,000 pounds of seed cotton

[19] In 1929 the gross farm income per farm from all sources averaged $1,571 for the 10 cotton States, and in 1934, $669. At the same time, the gross farm income for the remainder of the United States averaged $2,414 and $1,353, respectively.

[20] L. P. Gabbard and F. R. Jones, Large-Scale Cotton Production in Texas. Texas Agricultural Experiment Station bull. 362. 1927. 24 pp.

[21] Mechanization of Agriculture as a Factor in Labor Displacement, Monthly Labor Review 33 (4) : 749-783. October 1931.

a day, as contrasted to 125 to 150 pounds a day for the average hand picker. Until more machines are produced and more intensive studies are completed, the cost of picking a bale of cotton with the mechanical picker must remain in doubt. It is worth pointing out, however, that many cost items are involved, such as depreciation, interest on investment, normal repairs, taxes, housing, and insurance, all of which might be classed as overhead expenses. In addition, there are such direct operating expenses as operators' wages, tractor cost, value of cotton lint and seed left in the field, and the loss in value from lowered quality. It is the total of all these items in comparison with the cost of hand picking which will largely determine the final economic feasibility of the mechanical cotton picker. For the moment, however, we are concerned only with the possible effects of a successful picker, if and when introduced.

If we assume that cotton acreage will remain about the same, and that a successful machine will be produced in large quantities and sold to all who can afford to buy, tenant farming as it now exists in the South would undergo change. Some tenants and sharecroppers would still be needed as laborers in the cotton fields, but many would have to turn elsewhere for a livelihood.

Would they pour into the North and seek employment in industry? If so, what would be the effect on organized labor, wages, and standards of living among both skilled and unskilled workers? Many of the people from the rural South have had almost no experience with industrial discipline and complicated machinery; could they be trained to useful and self-supporting employment?

On the farms of the 10 cotton States are to be found 70 percent of all mules and 16 percent of all horses on farms in the United States. These 5,000,000 horses and mules, upward of 30 percent of the total number of horses and mules on farms in the United States, together consume annually the produce from approximately 25,000,000 acres of farm land. Will the cotton picker, necessitating the use of a tractor, force the elimination of a large percentage of these horses and mules, along with the hoe, the one-horse plow, and the great hordes of roving cotton pickers? If so, smaller acreage will be required to feed the working stock of the Nation.

The good and the bad effects of such a machine are not clearly and distinctly set apart. The cotton picker would cut down sharply the greatest single source of employment for woman and child labor in America. They could not compete with a successful mechanical cotton picker, especially in the river bottom areas of Mississippi and Arkansas, and in the Gulf coast prairie

FIGURE 19. Hand picking is slow and laborious.

and the Texas black prairie, where high acre yields and large plantations would probably encourage the adoption of new mechanical equipment. Their backs and their hands would be spared the labor. But how else, it may be asked, are these people to make a living? Would a larger percentage of them be driven into domestic service? Or might the mechanical picker result in employment of fewer members of a family, but these at better wages, thus releasing women and children for other tasks which might contribute to higher educational and living standards? This latter course is not improbable in view of the experience with advances in machinery in other agricultural pursuits.

These effects are based upon the supposition that the cotton picker will be rapidly introduced, privately purchased, and employed just as any other piece of capital equipment is purchased and employed. Perhaps arrangements can be invented which will help to distribute widely the profits derived from conserving human labor. Many questions which arise may never have to be answered if, as in the case of many improvements, the cotton picker requires decades rather than just a few years to get into common use. Given a long period of introduction the period for readjustment would be longer and individuals actually displaced by this labor-saving device might be absorbed elsewhere with only limited shock. The key to

FIGURE 20. Mechanical picking (with an experimental machine).

the degree of disturbance which the cotton picker will create, therefore, to a large extent lies in the length of the period of introduction.

Does the solution lie in whole or in part in the development of farm cooperatives, or more diversified farming? Will northern industry move into the South and take up the slack in the labor supply? Perhaps new industries will grow out of the small beginnings that have been made in air conditioning, large-scale production of prefabricated houses, and rural electrification—to the benefit of all parts of the country. A cotton picker would prove advantageous if, as millions were released from the cotton fields, new industries surged forward to employ idle hands.

II. THE MINERAL INDUSTRIES

By F. G. Tryon, T. T. Read, K. C. Heald, G. S. Rice, and Oliver Bowles [1]

The Double Task of Mineral Technology [2]

The task of mineral technology is to supply the fuels and the raw materials for which modern life has come to depend on the resources of the under-earth. Ours is the age of the power machine and the minerals furnish both the power and the metal for the machine. The minerals now supply 90 percent of the national requirements for energy—water power furnishing 10 percent. Aside from the manufacture of food products and textiles, the minerals have become the greatest of the raw materials of industry, the chief bases of chemical manufacture, the chief materials of construction. It is hard to imagine any activity of modern life which does not utilize either energy derived from mineral fuel or articles fabricated from mineral raw materials, and in large part the progress of invention has been an increasing ingenuity in devising means to use the energy or the exceptional materials made available by the mines. The story of such inventions built around the minerals is reserved for later chapters. In this chapter we shall stop with the delivery of the fuel or the material ready for use by other industry. This involves following the crude mineral through the stage of concentration, and smelting or refining, but not through subsequent shaping, alloying or fabrication. The contributions of mineral technology so defined are registered primarily in lowering the costs of other industry or in widening the range of useful materials available.

This primary service of mineral technology is understood even by the citizen whose direct contacts with the products of the mines and wells are limited to the purchase of fuel for his furnace or gasoline for his car. What the ordinary citizen does not understand is that mineral technology works under a constantly increasing handicap.

The miner faces a double task. He begins on the richest and most accessible of the known deposits and as these are exhausted turns unavoidably to leaner ores and thinner beds, or to less accessible deposits lying at greater depths or greater distances from market (fig. 21).[3]

Except as chance or patient exploration find other new deposits, equal in richness or in accessibility to those exhausted, mineral extraction always faces the prospect of increasing physical obstacles. In manufacturing every advance in technology assures a net gain in efficiency; in mining it may be offset by the increasing handicaps of nature. The miner is like a man rowing upstream.

Mineral economics, therefore, is the record of struggle between opposing forces. On the one hand is the factor of exhaustion, with its burden of accumulating handicaps. On the other is mineral technology, aided by its allies, exploration and transport. Finding of new deposits gives the mining engineer new ground to work upon and expansion of the transportation network may open up deposits known but previously inaccessible. The result of the struggle differs from place to place. In thousands of individual mines and scores of districts depletion has the best of it. If the world were dependent on the copper mines of Cornwall, or the silver-lead of ancient Laurium, the best of its technology could not avert a huge increase in price and a curtailment of supply. But taking the world as a whole, technology and its allies have generally the best of it, and their victory has nowhere been more striking than in the United States. Despite the exhaustion of many older districts and the forced resort to greater depth and lower grades of ore shown in figure 21, technology has provided American industry with an increasing quantity of mineral available at declining price. Down to the time of the World War

[1] The contributions of the several authors are indicated in the footnotes to the individual sections.

The data contributed by Messrs. Tryon, Rice, and Bowles and the charts presented in this chapter are preliminary results of the Works Progress Administration National Research Project on Reemployment Opportunities and Recent Changes in Industrial Techniques and are published with permission of the director of the project and the Director of the U. S. Bureau of Mines.

[2] By F. G. Tryon, U. S. Bureau of Mines.

[3] The data in fig. 21 are derived as follows: Average yield of copper at Calumet and Hecla mines from U. S. Geological Survey Prof. Paper 144, p. 80, and later published annual reports of the Calumet and Hecla Consolidated Copper Co. Note that because of consolidations effected, from time to time the record is not exactly comparable, because of inclusion in later years of properties with ores of naturally lower grades. However, the broad picture of declining yield in comparison with the early years of this famous district is undoubtedly correct. Average yield of all copper mines from E. W. Pehrson, U. S. Bureau of Mines, I. C. 6773.

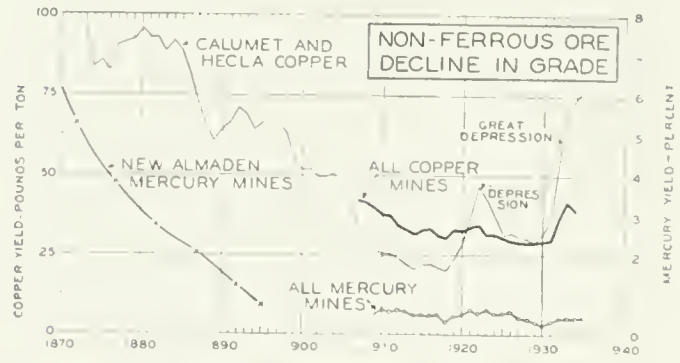
Average yield of mercury at New Almaden from J. W. Furness, U. S. Bureau of Mines, Mineral Resources 1927, pt. I, p. 62; at all mercury mines from annual mercury reports of U. S. Bureau of Mines, and a special compilation by H. M. Meyer.

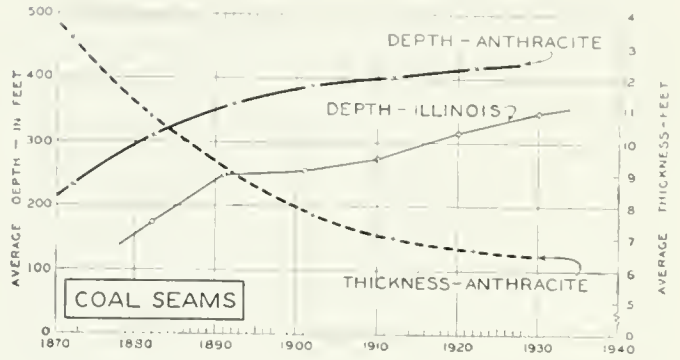
Average depth and thickness of beds at Pennsylvania anthracite mines from studies of D. C. Ashmead, summarized in Report of the U. S. Coal Commission (1925), p. 661, and extended by Mr. Ashmead to 1931 for use in the present study.

Average depth of Illinois bituminous mines computed by J. Edward Ely from annual coal reports of the Illinois Department of Mines.

Percentage of dry holes in drilling for oil and gas from annual petroleum reports of the U. S. Bureau of Mines (Mineral Resources, 1930, pt. II, p. 861) and U. S. Geological Survey Bull. 394, pp. 40–41.

the output of all the major minerals grew by leaps and bounds (fig. 22).[1] Thereafter anthracite and gold declined, and bituminous coal and iron ore checked their





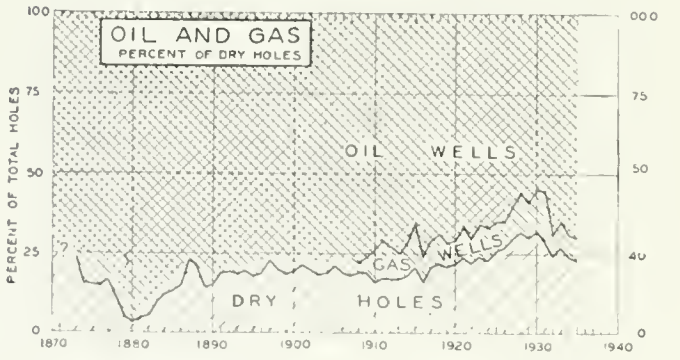


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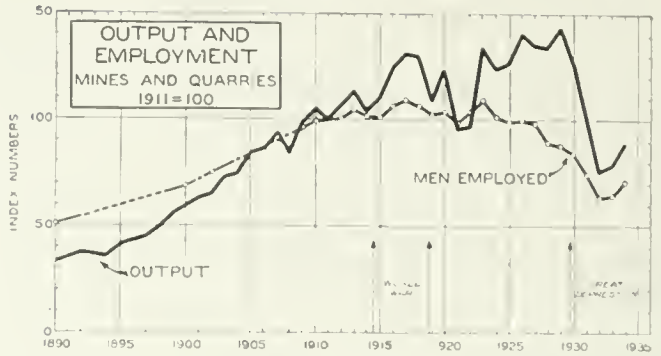
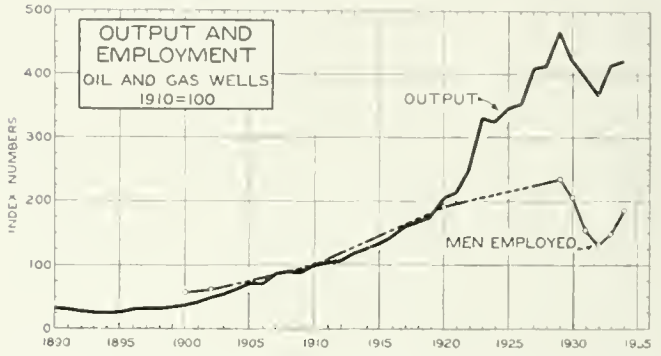
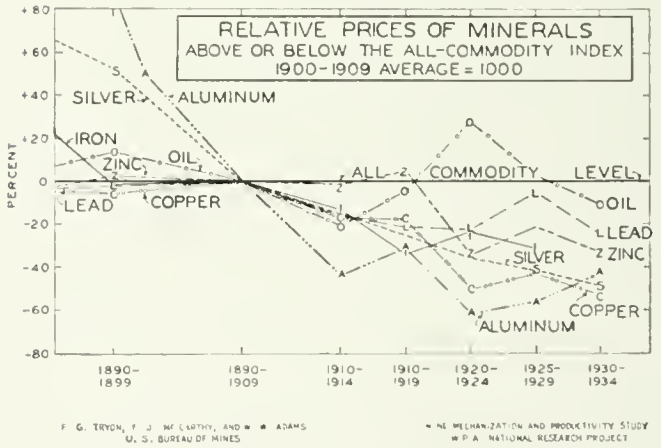
FIGURE 21. Indicators of the increasing natural difficulties in mining, 1870–1935.

Depletion of the rich and accessible deposits forces resort to leaner deposits at greater depth or greater distance from market. The chart shows the increasing natural difficulties of mining as indicated by increasing depth of shafts and diminishing thickness of seams in certain coal fields, the growing percentage of dry holes in drilling for oil and gas, and the declining yield of metal from nonferrous ores. The increase in grade of ore indicated for 1921, and for 1931 to 1934, are due to the effect of depression prices in shutting down high-cost mines or forcing the operator to practice selective mining of the richest portions of his ore body, thereby reducing the grade obtainable later.







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MECHANIZATION AND PRODUCTIVITY STUDY
W. P. A. NATIONAL RESEARCH PROJECT

FIGURE 22. Trend of production, number of men employed, and relative prices in the mineral industries, 1890–1935.

Despite the increase in natural difficulties, technology has been successful in supplying increasing quantities of the products of the underearth. Mineral output grew by leaps and bounds down to the end of the World War. During the 1920's production of oil and gas increased at an accelerated rate; production of other mines and quarries as a group slackened its former growth under the influence of changes in demand. (During the great depression all branches experienced a decline in demand.)

The number of workers employed reflects these changes in demand and also very great increases in technical efficiency. The number on the rolls of mines and quarries declined after 1923, while that at oil and gas wells continued to increase. (Employment data for oil and gas are preliminary approximations.)

Technical advances in most of the mineral industries more than suffice to absorb the increased difficulties of mining and prices of minerals have declined in relation to the all-commodity level.

[1] The data used in fig. 22 are derived as follows: Index numbers of mineral output (physical volume of production at mines and quarries and at oil and gas wells) are from an original study by F. J. McCarthy, U. S. Bureau of Mines, details of which are to be published later, and are subject to revision. Index numbers of men employed at mines and quarries are based on annual reports of W. W. Adams, Chief, Employment Statistics Section, U. S. Bureau of Mines, covering the period 1911 to 1934, and comparable data for the period 1889–90, 1900, 1902, and 1909–10, developed by F. G. Tryon from the Census of Occupations and Census of Mines and Quarries. Index of men employed at oil and gas wells is based upon the fragmentary observations of the Census of Occupations which are rough approximations only. Data on relative prices of minerals and other commodities compiled from various primary sources.

former rate of growth, but in many other lines advance persisted. The composite curve of all mineral production shown in figure 22 continued to rise down to the coming of the great depression in 1929. Certain components had, indeed, fallen away, but aside from gold, mercury, and, in some measure, anthracite, the slackening of output was due to changes in demand rather than to depletion.

While supply was increasing, mineral prices were declining in relation to the all-commodity level. Price movements of certain metals are recorded in the chapter on metallurgy and those for others are shown in figure 22.

The best index of the position of mineral technology is probably the output per worker, sketched for the principal minerals in figure 23.[5] With the exceptions of anthracite and mercury, all of the branches of min-

[5] Reproduced by permission from the section on Mineral and Power Resources, by F. G. Tryon and Margaret H. Schoenfeld, in Recent Social Trends (1932), p. 70.

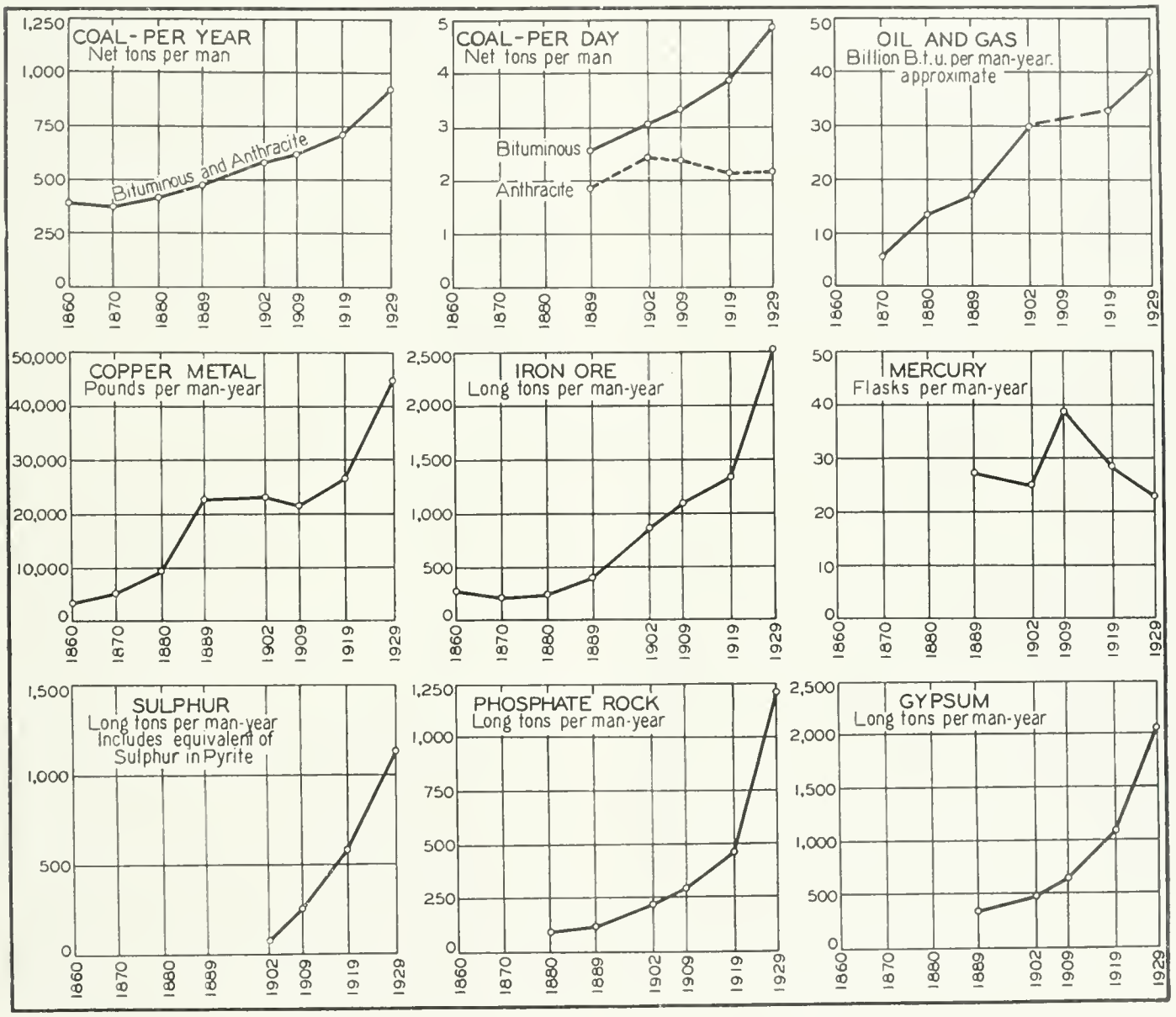

FIGURE 23. Trend of output per worker in the mines of the United States.

In most branches of mining, technology and discovery of new deposits have effected a large increase in the output per worker, the advance being accelerated in the decade following the war. Among the mineral industries shown, only anthracite and mercury mining exhibit a decline in the output per man. Both of these industries are characterized by advanced depletion.

The date for oil and gas are the roughest of approximations, but may serve to indicate the trend.

ing there shown exhibit a great increase in yield per worker. The gains in productivity are apparent beginning with the earliest record, but they seem to have been somewhat accelerated during the decade of the 1920's.

Prior to 1923, the labor force engaged in mineral extraction increased both absolutely and in relation to the working population as a whole. Thereafter, the combined effects of the acceleration of technique and the retardation of demand produced a sudden change and the number of workers engaged in the mineral industries declined from 1923 to 1929 (fig. 22). Of the major branches of mineral extraction, only oil and gas continued to provide more jobs. With the onset of the great depression, of course, both output and employment have decreased in substantially all branches except gold.

The change in demand for man-power is seen in the proportion of the national working force engaged in mineral extraction, summarized below.

Percent of the total gainfully occupied who were engaged in mineral extraction

Year	Percent	Year	Percent
1870	1.5	1910	2.6
1880	1.6	1920	2.7
1890	1.8	1930	2.0
1900	2.1		

Down to 1920 mining required a steadily increasing proportion of the working force. Since then the proportion has declined.

The future contributions of technology must therefore be weighed against the prospect of mounting difficulties. For the immediate future further gains in productivity of labor and reduction in cost seem reasonably sure. But in the longer view the machine civilization faces a challenge in the increasing handicaps of mineral depletion. Without painting a picture of gloom the prospect is that America will ultimately have to devote far more effort to the task of mineral extraction. The answer to the challenge is twofold: eliminate waste and improve technology.

The lines of technological attack vary with the different minerals. They include learning to find concealed deposits, penetrating to lower depths, using leaner ores or complex refractory ores by mass methods of mining and by improvements in concentration and smelting, recovery of byproducts, mechanization of work now done by hand, and reduction of the accident hazard. Safety in mines is not merely a humanitarian problem, for unless the hazard can be controlled, mining becomes physically impossible or cost abnormally high.

It is one thing to outline the task of technology, another to trace its probable success. Even the cautious observer who seeks to paddle in the charted waters of present trends may find himself swept downstream by a current of prediction into whirlpools that sink his fragile craft. The writer of this introduction recalls assumptions confidently made a decade ago which experience has already proven wrong. The hazard of forecast is especially serious in a field that involves not only the uncertainties of invention, but the unpredictable factor of mineral discovery, and it has led astray even so practical a mind as Edison's.[6] All that can well be done is to trace existing currents of technologic change, and to ask in what direction they seem to be sweeping the mineral industries. This is attempted in the following pages, each collaborator writing about the field that interests him most, and expressing, necessarily, his own judgments. First to be discussed is the general problem of the search for new deposits. Thereafter it will be in order to consider in turn the principal branches of mining, to mention the problems of mine safety, and finally to attempt a thumbnail sketch of the composite effects of the changes in process upon American life.

The Technique of Exploration [7]

Passing of the Old-Time Prospector.—Until recently the search for new mineral deposits depended chiefly on the adventurous efforts of the individual prospector. Most of the world's known store of metal was first discovered by men trained in the school of adversity but lacking either scientific or technical guidance. In areas where deposits outcropped at the surface, the principal metal-mining districts were found relatively soon after the region was occupied by people who knew the value of the metals. In North America the golden age of surface prospecting followed the discovery of the yellow metal in California and within the next half century a wave of exploration swept over the western United States, Australia, British Columbia, Alaska, and many other lands. Figure 24 suggests how large a part of the present source of metalliferous wealth in the United States was found in this way and how small, by comparison, have been the finds of the last quarter century. In the United States, at least, it is clear that the contribution of the old-time prospector, equipped with pick and burro has now been largely made, though the depression has sent thousands of men into the hills again to search for gold. Except as new methods for locating concealed deposits may be de-

[6] Mining and Metallurgy, November 1931, p. 508.

[7] By K. C. Heald, staff geologist, Gulf Oil Corporation, Pittsburgh, Pa.

veloped, the influence of the factor of discovery is slowing down.

In striking contrast to the metals is the record of discovery of the major oil pools, summarized in the same diagram. In this field the untrained individual could accomplish little. The short life of the typical oil pool and the growing demand for petroleum products furnished a powerful incentive for organized search and were a major factor in the development of new methods of exploration.

Rise of a Science of Exploration.—While geologic science has been applied for many years to the search for mineral deposits, the only industry which can be said to have organized a mass attack upon the problem is petroleum. Today, the oil industry employs thousands of geologists. Their effectiveness is proved by the fact that most of the petroleum currently produced in the United States comes from fields where no seepages of oil or of gas, the visible signs that attracted the early explorers, exist. The geologist is trained to consider every factor that is significant and has learned to recognize the promise of regions where there are no surface traces of these substances.

In other branches of mining also, there has in recent years been increased employment of men to search for mineral deposits. The State and Federal surveys have rendered valuable service, and the larger metal mining companies, in particular, maintain geologic staffs. If the experience of the petroleum industry is any criterion, this tendency, if continued and intensified, will have important results. While the search for concealed ore deposits appears inherently more difficult than for petroleum, it seems reasonable to conclude that the science of exploration for many types of minerals is in its infancy.

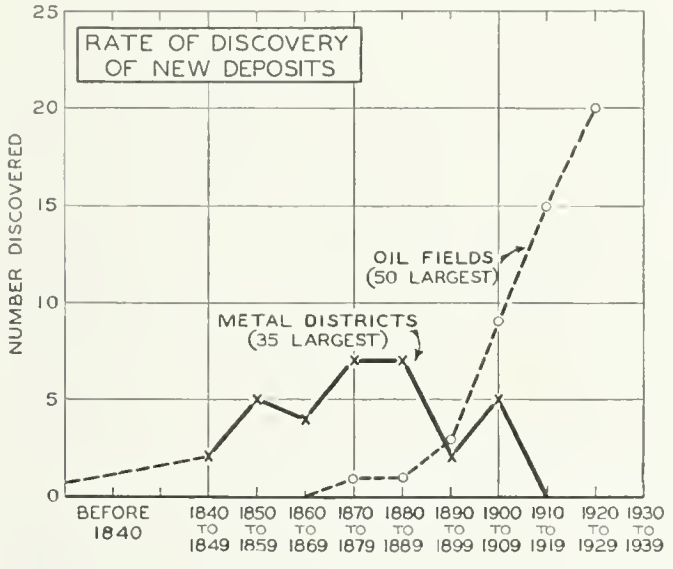

FIGURE 24. Trends in discovery of new mineral deposits as indicated by the number of major metal-mining districts and major oil fields discovered in each decade from 1840 to 1930.

In metal mining the discovery of new deposits is slowing down. Of the 35 leading metalliferous districts only 5 have been discovered since 1900 and none at all since 1910. In oil, on the other hand, discovery is still exceedingly active and out of the 50 largest pools 20 were discovered in the decade 1920–30.

Discovery of all the important mineral deposits in any given area is not today possible. Even were geology a mature science, it could discover only a fraction of the mineral accumulations, since the geologist must draw his deductions from conditions observed on the surface of the earth and in holes that penetrate, at most, but 10 or 12 thousand feet below its surface. If discovery is to be even approximately complete, geology must be supplemented by equipment and methods that will supply information about the rock conditions deep below the earth's surface, and these methods must secure the required knowledge more rapidly and more cheaply than the slow and costly procedure of drilling deep holes.

Methods of this character are at hand. The science of physics has come to the aid of the geologic prospector. The physicist, to satisfy his passion for precise and minute measurement, developed sensitive instruments to determine the pull of gravity, the effect of the earth's magnetic field, the rates at which vibrations could be transmitted through rocks of different types, and other measurable effects that may tell of conditions deep below the earth's surface. These instruments have enormously increased the resources of the trained prospector.

In some fields of exploration geophysical methods are now intensively applied. Millions of dollars have been spent on their development and application, and their use gives employment, directly or indirectly, to thousands in the United States alone. Their record of success is impressive when it is recognized that the methods are very young, that most of the geophysical effort to find mineral deposits has been concentrated in North America, and that more than nine-tenths of it has been directed to the search for oil or gas. Petroleum and natural gas deposits in foreign lands and deposits of other minerals everywhere, that can be found only through applied geophysics, remain to be discovered.

The first contribution of geophysics to the science of prospecting was the discovery of bodies of iron ore. Instruments that today would be considered crude were used to localize areas of high magnetic intensity. Underlying some of these areas bodies of iron ore were found. Although this method was the pioneer, its application has thus far been quite limited. Only one of the measurably magnetic quantities—the

vertical component of the earth's magnetic field—has been extensively studied, and there is still strong disagreement as to the origin and significance of the magnetic phenomena recorded by the instruments. The record of this method as applied to mineral discovery is not impressive but, in the writer's opinion, its future has more promise than its past might indicate.

Seismology is, today, more extensively used than other geophysical methods. This method permits the prospector to learn something about conditions at depths as great as 15,000 or more feet, although the information about those conditions is not precise. Under favorable circumstances the areas where conditions suggest the existence of oil pools, and even the approximate depth at which certain significant layers of rock, likely to be closely associated with petroleum, will be encountered by the drill, may be determined.

In spite of its achievements, applied seismology must be rated as a very imperfect science. In many areas consistent and understandable results cannot be secured. The theory upon which depends the interpretation of the results is incomplete, even with respect to the conditions in the oil-bearing areas where a great deal of work has been done, and much of the theory that will be demanded when seismology is intensively employed in the search for minerals other than petroleum unquestionably remains to be developed.

Methods which measure either the total force or some component of gravity have been strikingly successful only in coastal Louisiana and Texas, where oil fields are associated with great masses of salt. This salt is so much lighter than the rocks that surround it that the gravity effect is, in many instances, very easy to detect with the precise instruments now available. Modest successes have been scored in other areas, but it has been learned that translating gravity into geology is even more difficult than translating seismology into geology. These methods call for ultraprecision both in the actual physical measurements and in the thought applied to their interpretation. Unquestionably technique and theory thus far undeveloped will be needed when gravity is extensively used to find the ores of metals.

Methods that utilize measurable electrical properties of the earth, such as conductivity, resistance, and induced magnetism, have been tried with small success by the petroleum industry and have been, in large measure, discarded. It does not follow that these methods are without promise. However, the evidence most helpful in locating oil and gas fields could be secured at less cost and with greater assurance of accuracy in other ways. Electrical methods have a modest record of success in connection with the search for certain types of ore deposits but, in their present state of development, they appear to have a very limited field of application. The fact that far less time and money have been spent on their development than on either the seismic or gravitational methods probably means that their ultimate usefulness cannot be correctly appraised by their past record or their present limitations.

Future of Discovery.—If discovery of new deposits should cease today, proven reserves in the United States would meet the requirements of this country for a period ranging from perhaps 10 years for petroleum to probably more than 2,000 years for coal. However, discovery will not cease in any predictable time. In the year 1935 about 50 new oil and gas-yielding fields were found in the State of Texas alone, nor did discovery lag in other areas. In the petroleum industry we may safely count on great additions to reserves through discovery of unexploited pay sands in many of the fields that are now producing, both by deeper drilling and by intensive prospecting of strata already penetrated. The successes attained in petroleum offer hope that resources of other minerals may also be increased. Over the world as a whole there is a possibility of enormous additions to available reserves.

At the same time, we should guard against a too easy optimism, for the application of geophysical methods to the search for metals has encountered baffling obstacles of observation and interpretation. While the new geophysics is to be credited with finding numerous oil pools and with much success in the search for underground water supplies, it has found few new metal mines. With the instruments and the methods thus far developed, it has proved exceedingly difficult to find metalliferous ore deposits of any type when concealed at depth. For this reason we may anticipate that, in the search for metal, geophysical methods will first be applied to enlarging the boundaries of known mineralized areas. They have, for example, been used to locate a large extension of the gold-bearing formation of the South African Rand. In time, the methods so developed may be applied with greater chance of success to the far more difficult job of exploration in new areas where no sign of the presence of metal is afforded by the surface.

Insofar as world supply of the minerals is concerned, there is little cause for immediate anxiety. It is true that most of the accessible parts of the earth have been at least casually inspected by the prospector, but important deposits not accompanied by conspicuous manifestations must await discovery in those regions where exploration is made difficult by the inhospitality of man or of nature. These include the very cold areas where climate and lack of transportation make it hard to live and the surface covering

of tundra, moraine, and ice make it hard to observe; the tropics where heat, disease, and scant population make travel and even life precarious, and jungle and swamp conceal surface indications of minerals; and the hinterlands of civilization in parts of Asia, Africa, and South America where there is danger from unfriendly people. These regions are immense, and even the scanty attention they have received has proved they contain important supplies of minerals. However, before they are explored and their mineral wealth made available, those areas that are more accessible will be more intensively and scientifically prospected.

It is believed that the intensive geologic attack, aided by an aggressive technology, may reveal new types of mineral deposits and that the geophysical attack will reveal mineral resources that cannot be discovered by existing methods.

Ultimate exhaustion of many minerals is inevitable, but in no case will exhaustion be catastrophic. Many important minerals maintain their commanding position, even today, only because they are slightly cheaper or have slightly superior qualities to those of other substances that are available in abundance and that are clamoring for a market.

The cost of intensive exploration will tend to concentrate discoveries in the hands of organizations financially able to stand a heavy, long-continued outlay before compensating returns are realized. Judging from the experience of the petroleum industry, continued advance in methods and effectiveness of discovery is intensified by the profit motive. Such advance will demand an increase in the number and scope of research laboratories, since fundamental research is essential to the successful adaptation of geological and geophysical methods to mineral discovery. Work of this type can be effective only when there is steadfast purpose and uninterrupted financial support, conditions which are often best found in the research organizations of private enterprise. At the same time, fundamental research should be strengthened under academic and governmental auspices.

It is to be anticipated that improved prospecting methods will rejuvenate some inactive areas and will bring important activities into areas now unoccupied. They will force some development of highways, railroads, and pipe lines. They will probably result in some increase in the number of small centers of population.

Technology in Coal Mining [8]

In coal mining present technologic development centers around machines to reduce hand labor. Limitations of space compel restricting our discussion to bituminous coal, though it will be understood that essentially parallel developments are in process under the sharply different physical conditions of the anthracite mines.

Strip or Open-pit Mining.—The substitution of power for human muscle reaches its maximum in strip or open-cut mining. In limited areas where the coal seam lies close to the surface, the overlying dirt or rock may be removed with power shovels and the coal loaded into cars or trucks, usually with smaller shovels of the same type. The use of open-cut methods is expanding, both in coal and in certain branches of metal mining (see fig. 28). The lines of technical advance have included the application of caterpillar mounts, replacement of steam by electric power, development of machine methods of shifting the tracks on which the coal or ore cars enter and leave the pit, or even elimination of the tracks by use of motor trucks. But the most important change has been the simple evolution in the size, power, and range of the shovel. Capacity of the dipper of the largest shovels has increased from a maximum of about 4 cubic yards in 1914 to 32 cubic yards, and the physical limits have not yet been reached. These enormous machines can handle not only dirt but sometimes beds of limestone and shale and permit the removal of 50 feet of overburden to recover a 5-foot seam of coal.

The immediate outlook points to further expansion of stripping as opposed to underground mining, though the long-run outlook is for exhaustion of the areas which can be worked by stripping. As the thickness of the overburden to be handled increases, the costs of stripping mount, and ultimately expansion of stripping will be checkmated by the competition of underground methods, which are also undergoing improvement. The rise of open-cut mining poses an obvious problem of technologic unemployment. Only a half or a third as much labor as in underground mining may be required, and where conditions are especially favorable the method provides the cheapest fuel and metal thus far attained.

Open-cut mining recovers a high percentage of the mineral resource but dissipates the soil resource. In some cases the surface has little or no value for agriculture, but in still others it may be excellent farm land. Present practice leaves behind an irregular waste of barren subsoil, mixed oftentimes with broken rock, on which vegetation of any kind is slow to reestablish itself. It is estimated that a total of 30,000 acres of land has been thus devastated by the mining of bituminous coal and lignite in the Mississippi Valley and Eastern States. In Illinois the total area suitable for stripping, and subject therefore to devastation, is estimated at 183,000 acres, about equal to the area

[8] By F. G. Tryon. The writer is deeply indebted to L. N. Plein and F. E. Berquist for information and criticism.

recently reclaimed by the Italian Government in the draining of the Pontine Marshes. Some effort has been directed to planting the strip spoil banks with timber or fruit trees, but the scale of such measures of restoration in the United States is so far very small in comparison with the need.

The Miner's Task Underground.—The underground work of coal mining is divided among two main groups of workers: The miners proper or "tonnage men" who dig the coal at the working face, and the "day men" who carry on the auxiliary tasks of haulage, ventilation, pumping, power supply, timbering, and maintenance. Among the tasks of the day men, the chief field of mechanization has been haulage. Animal power has given place to mechanical traction on main-line haulage in all but the smallest mines. Even in the gathering of cars from individual working places to be made up into trains, the mule is rapidly giving way to the faster and more powerful electric locomotive, and low-built machines have been developed for use in thin seams. In some areas electrification of haulage is now approaching the saturation point. A prospective change to Diesel locomotives will be discussed later in connection with mine safety. Another line of expected development is increased use of belt or trough conveyors for transporting coal from the face to central loading points, or even to the surface.

At present the most active field of mechanization relates to the work of the men at the face who constitute, under the system of hand loading, from 50 to 70 percent of the entire working force. To understand the great changes that are in prospect it is well to fix in mind the principal steps in the work of the old-fashioned pick miner in the bituminous coal fields. Generally, though not always, he took care of his room, setting the necessary props and incidentally carrying the track forward as the face advanced. (Sometimes, where the roof was too low or other conditions prevented the mule or the earlier types of locomotive from entering his room, he was expected to push the empty mine car up to the face, and push the loads back.) The labor directly associated with digging the coal involved three main tasks: Undercutting the seam, boring shot holes and preparing the charge of powder, and shoveling the coal when broken down into the mine car.

The Cutting Machine.—The first of these tasks to be mechanized was the undercutting of the seam. Lying on his side, the old-time miner was expected to cut with his pick a horizontal slot or kerf some 2 or 3 feet back under the bottom of the seam so that when loosened it would fall. This arduous and also very dangerous task early attracted the attention of inventors. Practical cutting machines were introduced in the late eighties and have undergone steady improvement. From 5 percent in 1891, the year of the first statistical record, the proportion cut by machine gradually increased to 84 percent in 1934. In the meantime the machines available have so increased in size, mobility, and speed that the average daily tonnage per machine has been multiplied threefold (fig. 25). Machines are now available which will make horizontal cuts anywhere in the coal face, and also vertical shearing cuts either in the middle or along the side of the room, thereby increasing the proportion of lump coal and facilitating the subsequent task of loading. In most districts, the cutting machine is now about as widely used as conditions permit (in some fields it is not readily applicable) although improvements in design and steady replacement of less efficient types will doubtless continue. We mention the cutter and plot its course in figure 25 because it illustrates the time often required to bring a new machine into general use.

The miner's next task, the drilling of shot holes, is still generally done by hand with a long steel auger. But where haulage has been electrified it is a simple matter to bring power to the face and to bore the holes with an electric drill. This practice has now extended to something like 15 or 20 percent of the total output and seems destined to spread over most of the industry.

To prepare the shot itself requires considerable time, but little or no strength. There is a tendency, however, to provide the miner with prepared cartridges and clay ready for tamping, and to assign the task of setting off the charge to special shot firers, sometimes when the main shift has left the mine. To permit blasting while men are at work, mechanical substitutes for powder have been developed, such as cylinders of compressed carbon dioxide or air, which can be discharged with shattering effect.

Mechanical Loading.—After the coal is shot down, comes the greatest of the hand miner's tasks, that of shoveling the coal into the mine car. This involves lifting the coal vertically a height from 2 to 5 feet and casting it horizontally perhaps 6 or 12 feet. The tonnage handled each year equals the total weight moved in excavating the Panama Canal, and until recently this work was all done by human muscle. At a wage of $5.50 a day, the mechanical work developed by the miner in this task costs the equivalent of about $7.50 a kilowatt-hour. So great and so heavy labor was early a target for inventors, but the cramped space and other obstacles to movement underground defeated efforts at mechanization until recently, and long after the work of undercutting was successfully mechanized, hand loading continued to require armies

of heavy labor. As late as 1923, hand shoveling in the coal mines was the largest single task of some 490,000 men.

The first machine for loading in rooms to attract public notice appeared in 1903 but disputes with the mine workers over the wage rate to be paid and operating difficulties prevented its adoption. Other machines were in use privately by 1918, but the commercial application of the mobile-type loading machine may be said to date from 1922 when the first machines designed by Joseph F. Joy appeared upon the market.

The number and variety of the machines now available is surprising. There are machines designed for driving entries and for loading in rooms, and still others for long-face work; machines designed to move on rails and others with caterpillar mount which crawl about under their own power. They include mobile loading machines which pick or push the coal onto an elevating conveyor, or gather it up by the motion of ingenious clawlike arms; the underground power shovel which braces itself between the roof and floor with a hydraulic jack, thrusts its scoop into the pile of broken coal, swings around and ejects the load into the waiting mine car; the duckbill attached to a shaker conveyor which shuffles its way under the pile of coal; and the scraper, dragging the broken coal to a loading platform at the end of a long face.

These machines, where successfully employed, virtually eliminate hand shoveling, except for incidental clean up. Still other machines, although not abolishing the use of the shovel, greatly reduce the labor. Material savings are made by portable elevating machines known as pit-car loaders. With this type of machine the shoveler need raise the coal only a few inches from the floor to a conveyor which then lifts it into the mine car. Finally there is the hand-loaded face conveyor, first used in the United States in 1905 and later reintroduced from Europe about 1911, which if it does not eliminate the hand shovel at least cuts down the labor by reducing the height to which the miner must lift the coal, and the distance to which he must cast it. The face conveyor also serves to transport the coal from the face out to a main conveyor, or to the power haulage way along the entry, thereby eliminating the heavy task of car pushing sometimes required and otherwise facilitating transport. For these reasons the face conveyor is especially useful in thin seams. It is probable that the savings ultimately possible have not yet been realized in many conveyor installations.

The tonnage of bituminous coal loaded by use of machines of all of these types has increased from 1,500,000 in 1923, the year of the first statistical record, to 47,000,000 in 1935, and now amounts to 13.6 percent of the underground production. (The tonnage of Pennsylvania anthracite similarly loaded has increased to 9,300,000 or 21 percent of the underground output.) For the industry as a whole, the new machinery, therefore, is just getting under way. That it is destined to spread very widely is shown by the fact that in some districts the great bulk of the output is already mechanized. In 1935, 90 percent of the Wyoming production was mechanically loaded, 62 percent of the Indiana production, and 56 percent of the Illinois production.

The process of trial and error is adapting the new machinery to the widely varying conditions of different mines. Present indications are that the scraper type is not likely to expand much further, for, unless the bottom is hard, it gathers dirt along with the coal; that the pit-car loader is an intermediate stage to be replaced later by full mechanization; and that the types most likely to find ultimate acceptance are the mobile loader, the duckbill-equipped conveyor, and various

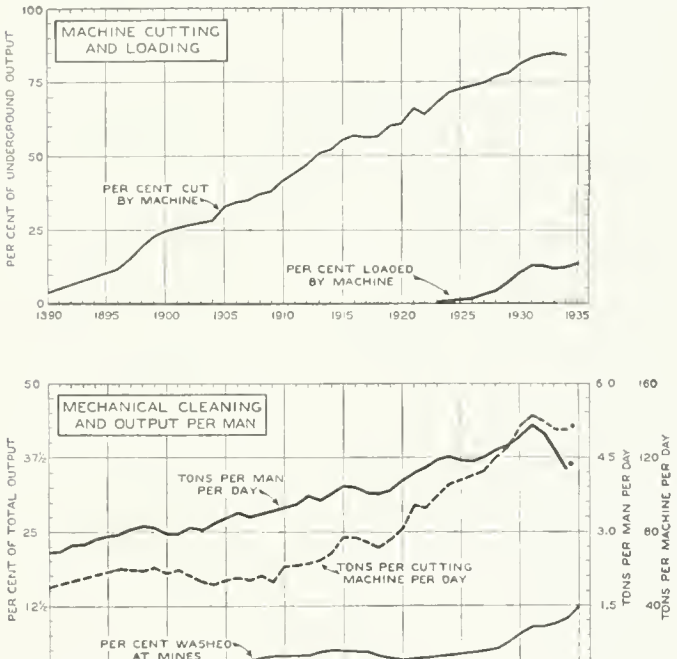
MACHINE CUTTING AND LOADING
PER CENT OF UNDERGROUND OUTPUT
PER CENT CUT BY MACHINE
PER CENT LOADED BY MACHINE
MECHANICAL CLEANING AND OUTPUT PER MAN
PER CENT OF TOTAL OUTPUT
TONS PER MAN PER DAY
TONS PER CUTTING MACHINE PER DAY
PER CENT WASHED AT MINES
TONS PER MAN PER DAY
TONS PER MACHINE PER DAY
TRYON AND PLEIN U. S. BUREAU OF MINES
MINE MECHANIZATION AND PRODUCTIVITY STUDY W.P.A. NATIONAL RESEARCH PROJECT

FIGURE 25. Technologic trends in the bituminous coal mining industry (excluding strip mines).

The undercutting machine, introduced in the late 80's, has now about reached the saturation point. Its course is being followed by the loading machine, introduced commercially about 1922 and now affecting 13 percent of the output. Loading machinery of one type or another seems destined to spread over virtually all the industry. Parallel advances have occurred in mechanical cleaning by washing.

The result of these factors is a notable increase in the output per man per day which bids fair to continue. Meantime, the increase in the size and efficiency of machines is indicated by the growing tonnage per cutting machine per day.

The decrease in daily output per man and per machine after 1932 is associated with the shortening of hours following the N. R. A. code.

forms of hand-loaded face conveyors, which perform functions of transport as well as of loading. Selection from the alternative types is governed largely by seam conditions. Oftentimes two or more types may be advantageously used in the same mine, and locally there are signs of a tendency to combine mobile machines for loading with conveyor units for initial transportation of the coal. In some veins obstacles may possibly prevent the use of such machinery, but the opinion may be hazarded that by one device or another the great majority of the larger mines can be mechanized, with a capacity sufficient to supply the national requirements. It must be recognized, however, that much time may often be required to find the right type of machine, to make the radical changes in mining practice necessary and to train men in its use. There are also many old mines where short expectancy of life and the cost of changing over the existing layout would outweigh the possible saving. Technical difficulties and inertia, therefore, combine to force a lag between invention and application. Truck mines serving a local market may survive with hand loading by virtue of their advantage in shipping costs.

The rate at which the mechanization of loading can go on within a given area depends partly on the wage rate. The districts of the West where mechanical loading has now become general were marked by relatively high wage rates, and conversely the districts where wage rates were low, found little incentive to mechanize. With the recovery in wage rates which began in October 1933, sales of equipment have multiplied and numerous companies in the East and South that formerly saw no advantage in mechanical loading are now installing machinery. In 1936 more machines have been sold in West Virginia than in any other State.

Some light on the possible rate of increase is thrown by the past record of the introduction of the cutting machine given in figure 25. The first 10 years of the loading machine have followed a course much like that of its predecessor. It is well to remember, however, that the cutting machine had to make its way in an industry which was just beginning to use electric power. The loading machine enters at a time when primary haulage is already electrified in all but the smaller mines, making the task of bringing power to the face comparatively easy. The loader may therefore spread more rapidly than did the cutter.

Another new machine is the coal saw, a very thin cutter which is used to sever the block of coal on two, three, or four sides, instead of on one or at most two as is now done with the standard cutting machine. Saws have been introduced, but are not yet used on a substantial scale.

Mechanical Cleaning.—Mechanical loading underground has also stimulated changes in the work of preparation on the surface. The hand miner was expected to watch for pieces of slate or boney coal as he shoveled, and to throw them back into the waste. The loading machine could not do this, and where the amount of impure material was serious, it became necessary to transfer the work of removing it to the surface. The change came at a time when inventors were already engaged on the task of improving quality by the reduction of ash and sulphur, and when new methods of mechanical cleaning were under way. The fundamental problem is to separate the coal from the slightly heavier impurities, and the agencies used have included shaking tables, moving currents of water and of air, and a suspension of fine sand in water, which floats the coal like a heavy solution. Such methods are found to be the only practicable way of cleaning the smaller sizes, though for the sizes above about 4 inches, picking by hand on a conveyor table remains the best method. The tonnage of bituminous mechanically cleaned has increased from 3.8 percent of the total output in 1906 to 12.3 percent in 1935 (fig. 25), and further extension is assured.[9]

Minor developments in the general field of preparation include removal of dust by air or by treatment with calcium chloride, or with oil sprays, and the appearance of "packaged fuel"—cube-shaped briquets wrapped in paper.

It will be understood that at the same time marked advances have occurred in the preparation of Pennsylvania anthracite. Indeed, the art of coal preparation in America largely developed in the anthracite region, where natural conditions and market preferences stimulated great attention to the sizing and cleaning of the coal.

Some Social Consequences.—The mechanical changes under way in the bituminous coal mines constitute a major technical development. Mechanical cleaning yields a better and more uniform product, mechanical loading reduces the cost.

At a wage rate of 80 cents an hour, savings with the large mobile machines that entirely eliminate hand shoveling are claimed in the order of 15 to 55 cents a ton. Against this must usually be set some sacrifice in sales prices or an increase in cleaning costs. The loading machine usually results in a smaller proportion of lump coal, and it often increases the percentage of ash so much that the operator must install mechani-

[9] As only the smaller sizes require mechanical treatment, the total production of the mines equipped for mechanical cleaning represents a much larger fraction of the national output—24 percent in 1935. For this reason the curve of percentage mechanically cleaned in fig. 25 is plotted on a larger scale than the percentage mechanically cut and loaded.

cal cleaning at a cost of perhaps 10 or 20 cents a ton. But there remains under favorable conditions a material saving. Savings with pit-car loaders or conveyors are smaller. Wage rates being equal, therefore, these inventions point to reduction in price to the consumer. The actual course of prices depends largely upon the course of wages, and as wages in some districts fell during the depression to bare subsistence levels, future prices may be higher than the depression low despite the savings in the man-hours required to produce the coal.

The machines introduce new accident hazards. They may raise enough dust to be trying on the men. They may also influence the percentage of coal recovered in mining. Under some conditions, the use of face conveyors permits the mining of thin coal now regarded as unworkable. Under still others, use of the mobile loader, especially, may induce practices that decrease recovery. The question deserves further study, for the wastes of coal in mining are already grave—the avoidable losses in the bituminous mines averaging 20 percent, or 150,000,000 tons in an ordinary year.[19]

Overshadowing other social effects is the possible influence upon the mine workers. The short-run effect is to inject an element of technologic unemployment in an industry where other factors have already reduced the number of jobs. The decline of 247,000 in the number of men employed at bituminous coal mines since 1923 is due chiefly to other causes—to the liquidation of surplus capacity created by the war and to changes in demand associated with fuel efficiency, oil and gas competition, and the depression of general business. These other causes have thus far overshadowed the factor of technologic displacement, yet it is clear that the introduction of mechanical loading does work to curtail jobs. Any attempt to estimate the extent of such displacement requires much more accurate data than are yet available. A few mines which passed from 100 percent hand loading to 100 percent loading with mobile machines show a reduction in the man-hours required per ton of coal amounting to about 35 percent in the course of 10 years. How far these are typical it is not yet possible to say. Displacement with pit-car loaders and conveyors appears to be much less, while mechanical cleaning usually works to increase the number of jobs.

No forecast can be attempted here of the amount of future labor displacement or of the rate at which it can proceed. The answer depends on many imponderables, such as the future of demand, improvements in the machines, the bargaining power of the mine workers, the wage rate, and the hours of labor. The history of the cutting machine indicates that it may be many years before the introduction of the loading machine is complete. Yet it would indicate, also, that except as other factors operate to spread the available work, the new machines may locally create a definite problem of unemployment. Obviously, this will be most apparent in districts where hand loading is still entrenched.

At the same time, it is clear that to attempt to block the advance of mechanization would offer no solution for the difficulties of the industry. Unless it is proposed to throw the entire burden on the mine workers by cutting wage rates, mechanization is the chief hope of meeting the competition of other fuels or other coal fields paying lower rates. It is a striking fact that in Wyoming, Montana, Illinois, and Indiana the only mines which seemed clearly able to survive the intensely competive conditions of the last decade—aside from strip pits and little truck mines—were the mines that managed to mechanize. They have maintained employment far better than the mines which were unable to adopt the new technique. In any district where costs can be reduced by mechanization, failure to mechanize in the face of competition may actually reduce employment more than mechanization itself.

The long-run effects of mechanization are clearly favorable to the miner. They lighten his arduous task, increase his productivity, facilitate the payment of adequate wages, and strengthen the industry's position in competing with other fuels. Technologic progress is essential to meet the growing market pressure from petroleum and natural gas. Helping to offset the displacement of jobs in the mines is the additional employment generated in manufacturing the new machinery.

The loading machinery likewise affects the kind of worker needed. Certain of the old skills are no longer required though familiarity with the customs and the dangers of life underground remains essential. The machines put a premium on quick-reaction time, adaptability, intelligence, mechanical knowledge, and ability to work under supervision. They favor younger men and the prospect of working up to machine jobs tends to attract youths with better education who formerly had no interest in the mines. Older men without machine experience are handicapped and it is possible that the young men now recruited for service with the machines may be superannuated at an earlier age than prevailed under hand loading. The changes in character of the working force will be discussed further in recapitulating the effects of technology upon the mineral industries as a whole.

[19] Rice, George S., Fieldner, A. C., and Tryon, F. G., Conservation of Coal Resources, Third World Power Conference, Washington, D. C., 1936.

Petroleum and Natural Gas [11]

Technique of Oil and Gas Production.—The simple technique for drilling oil and gas wells and for recovering those minerals, that was practiced during the early days of the petroleum industry, is changing rapidly. For example, operators now undertake to drill wells 7,000 to 10,000 feet deep with as much confidence as was felt, a few years ago, in undertaking to attain less than half those depths. The changes are less in fundamental method than in improvement of design and quality of equipment and better understanding of the difficulties that must be overcome. The equipment and materials now available are strong enough to withstand the stresses that would normally be expected in a well 15,000 feet deep, which is more than 2,000 feet deeper than the deepest hole yet drilled and 5,000 feet deeper than the deepest well yielding oil or natural gas.

Improvement in understanding of the difficulties to be overcome and in design and application of methods and instruments to combat those difficulties have kept pace with improvement in equipment. Most deep holes are surveyed periodically as drilling progresses, and the drilling operations are so conducted as to insure the verticality of the bore; practices have been devised to decrease the number of holes that are lost due to drilling equipment sticking or twisting off in the hole; the experienced drillers now detect the imminence of blow-outs of high-pressure gas which, in the early years, wrecked many drilling wells and were a substantial cause of human casualties, and take steps that either prevent or control the explosive escape of gas: cements and technique have been developed that will permit the casing in deep wells to be securely anchored in spite of the high temperatures characteristic of great depth; and each of many minor improvements has added its bit to the technology of deep drilling.

The improvement in methods of increasing the flow of wells, when once drilled, has been equally remarkable. The percentage of wells that, a few years ago, would have been abandoned as dry or, at best, would have been very small wells has been sharply decreased. In some areas that were practically abandoned a few years ago because profitable production could not be secured, excellent wells are now being completed in pay sands once considered worthless. In other areas wells which apparently were approaching the end of their productive life have been rejuvenated.

Improvements in discovery methods promise to be even more important than improvement in completion technique. We now know that in the past many prospective wells were abandoned because of an erroneous belief on the part of the driller either that oil or gas pays had not been penetrated by the hole, or that their nature was such that profitable production was highly improbable. Various practices and instruments have been developed and successfully applied, proving that the criteria on which the early driller pinned his faith were not dependable, and as a result oil is today being discovered in holes that, in the past, would have been abandoned as absolute failures. This both increases the available supply of petroleum and gas and reduces the losses of the oil and gas industries.

The technique of producing the oil from wells is also being revolutionized. Scientific analysis of the conditions that control the occurrence of oil and gas has indicated many desirable modifications of traditional practice. The immature stage of the attack is manifested by many of the treatises and discussions dealing with the conditions that affect the business of recovering oil and gas from their sands. There is a tendency, characteristic of adolescence rather than of maturity, to theorize far beyond proved facts, but the trend is healthy and toward improved effectiveness.

One of the manifestations of this changing technique is the recognition of the role of natural gas in forcing oil from the underground reservoir. Wastes of gas continue on a very large scale, but from economic more than technical causes, and great progress in the conservation of gas pressure, and in the use of gas itself has been made. Another change is the willingness to take oil slowly from a well, in spite of the delayed return on the invested capital, if thereby an increased ultimate recovery may be hoped for.

Many very important problems are just beginning to be recognized. For example, it is now known that rarely is an oil-bearing sand uniform in texture. Laboratory studies indicate that oil and gas will be exhausted from the coarser-textured layers of the sand, and that water will invade these layers and appear in the oil wells long before the finely textured layers are depleted of their oil. Under such circumstances it is to be expected that after a period so much of the fluid pumped from a well will be water that the operation will not return a profit and the well must be abandoned, leaving behind much of the oil in the fine-grained pay. No effective method for combating this condition has been developed. In fact, no serious attack has been attempted.

During the past few years there has been a growth of the activities designed to recover oil from fields that, under traditional methods of operation, would be regarded as almost or quite exhausted. It has been proved that in many of these old fields much more oil

[11] By K. C. Heald, staff geologist, Gulf Oil Corporation.

is left in the sands than is recovered from the wells. Injection of gas and of water under pressure has substantially increased recovery in some areas, but a huge volume of oil is left behind by even the best of present methods. Increased effectiveness can come only with increased knowledge of the laws that govern the occurrence of oil in rocks and that will permit its recovery from the tiny interstices in which it is trapped. There is an encouraging increase in the number of operations designed to recover oil from semi-depleted fields and in the research under way in company laboratories and educational centers.

The trend is toward more scientific operation. We may say that the possibilities of applied science in the field of oil and gas production are just beginning to be appreciated, and may predict that the scientific attack will be intensified. It should lead to the employment of more technically trained men, both in the field and in the laboratory, and also should demand an increase in unskilled labor due to the development of new practices. In short, the petroleum and natural gas industries will benefit from technologic employment.

Present developments indicate that we may look forward to a great deal of activity, not only in new fields but also in old, semi-depleted fields with necessary employment of capital and labor. There will also probably be an increase of the small industries furnishing special service to the oil and gas industry—consulting laboratories, well cementing companies, well surveying organizations, casing perforators, and others.

Pipe Lines.—The fluid nature of oil and gas early led to the development of a specialized form of transportation to carry the product from field to refinery or place of use. The pipe line systems form an essential part of the petroleum and natural gas industries and in most instances are closely integrated either with the stages of production or with refining and distribution, or with both. The evolution of pipe-line transportation is one of the chief technologic contributions of oil and gas engineering. Technical improvement has developed step by step from small beginnings, and has gathered momentum in the last 15 years, as indicated for example by the increasing radius of transmission of natural gas. Among the specific advances are the introduction of welded joints, higher operating pressures, labor-saving machinery in trenching and in laying pipe, and the appearance of thin-walled, seamless pipe of high-carbon steel in diameters up to 24 inches. The growth and present extent of the pipe line systems are shown in the maps and charts of the report on transportation, which discusses the pipe lines in greater detail as a part of the transportation equipment of the country as a whole.

Indicators of the rapidity of technical advance in the oil and gas industry are given in figure 26.[12]

Refining.—Petroleum refining in America was born in 1855, before the first commercial oil well was drilled, when Benjamin Silliman, Jr., of Yale University, determined that "rock oil" sent to him from Pennsylvania could, by distillation, be separated into fractions some of which were suitable for the production of gas, for illumination, and for lubrication. The scientific attack on refining problems has steadily intensified and it is stated that today "in the United States chemical work in petroleum and related fields equals in quality, as well as in volume, the chemical work in all other fields combined."[13] Petroleum refining is therefore very properly discussed in a later chapter dealing with chemical engineering and the present chapter need sketch only its relations to the primary task of mineral technology in developing the resources of the under-earth.

The record of the response of the refining industry to the creation of new needs augurs well for its future productivity. For years the products needed from petroleum were kerosene and lubricants. These needs were met and products that could not be utilized were wasted. However, knowledge of the nature and availability of gasoline permitted the invention and development of the internal-combustion engine. The great and persistent increase in demand for gasoline was met in part by discovery of additional crude oil, and in part by invention of the cracking process. Were it not for cracking, refiners would, today, have to process almost twice as much crude oil in order to supply the demand for gasoline. (See fig. 26.) The possibilities of additional benefits from this process are far from fully explored.

Characteristics of gasoline obtained by cracking permitted modification of engine design resulting in economies of construction and performance, lowering both the initial cost and the cost of operation of automobiles. Additional progress in this same direction is promised by polymerization, a newcomer. Products supplied by this process have permitted important changes in design of aeronautic engines—changes

[12] The data in fig. 26 are derived as follows: The depth to the shallowest pay sand in new pools found is computed by N. D. Fitzgerald from records of 706 oil pools described in "Petroleum Development and Technology", Transactions, American Institute of Mining and Metallurgical Engineers, vol. 118, 1936. All pools for which depth of shallowest producing horizon was reported have been included. The record of deepest wells is from DeGolyer, "Historical Notes on the Development of the Technique of Prospecting for Petroleum," quoted by Pogue. Fuel consumption per barrel of crude run to stills is from F. G. Tryon and H. O. Rogers "Statistical Studies of Progress in Fuel Efficiency," Transactions, Second World Power Conference, vol. VI, p. 244, Berlin, 1930, with data for 1930 to 1934 supplied by N. Yaworski. Percentage yield of gasoline from G. R. Hopkins, annual petroleum reports of U. S. Bureau of Mines, with data from Census of Manufactures prior to 1916.

[13] Hopkins, M. B. Chemical Trends in the Petroleum Industry, World Petroleum, July 1936.

that could not be considered practicable before both the quality and quantity of the fuel supply for these improved engines were assured. It is believed that improvement in automotive engines will follow the road opened by the aeronautic engineer.

The development of lubricants has been equally important. In fact, technology does not at present know of processes that could supply our needs for lubricants from raw materials other than petroleum. The present trend is to refine petroleum so that the yield of gasoline will be as great as possible, at the expense of all other possible petroleum products. When

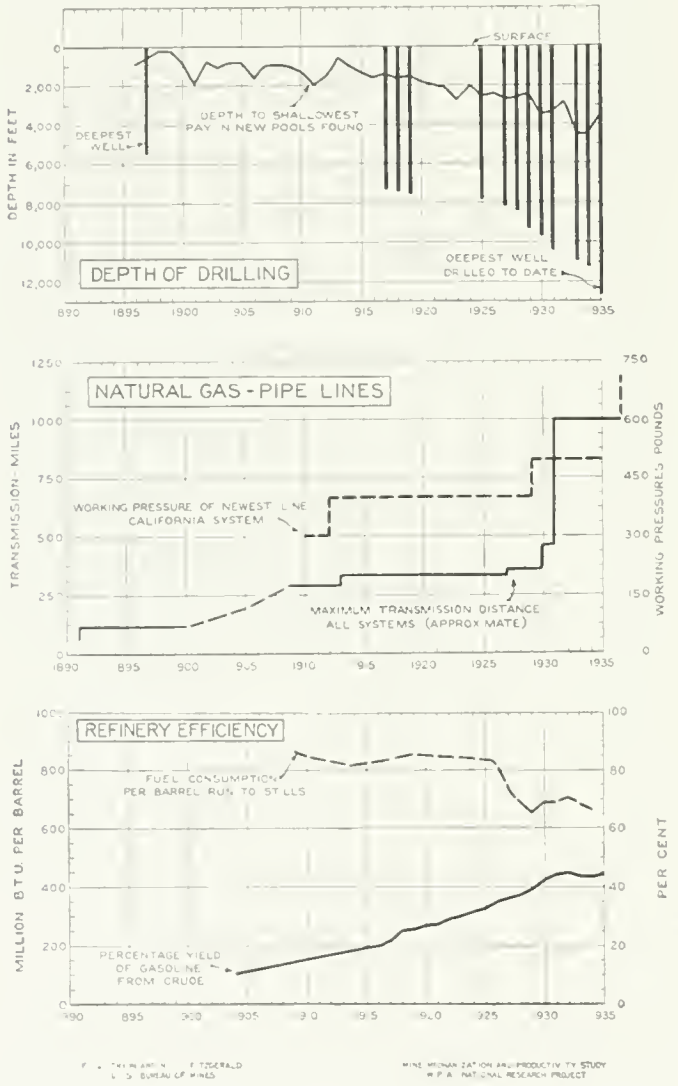
DEPTH OF DRILLING
DEPTH IN FEET
SURFACE
DEEPEST WELL
DEPTH TO SHALLOWEST PAY IN NEW POOLS FOUND
DEEPEST WELL DRILLED TO DATE
NATURAL GAS - PIPE LINES
TRANSMISSION - MILES
WORKING PRESSURES - POUNDS
WORKING PRESSURE OF NEWEST LINE CALIFORNIA SYSTEM
MAXIMUM TRANSMISSION DISTANCE ALL SYSTEMS (APPROXIMATE)
REFINERY EFFICIENCY
MILLION B.T.U. PER BARREL
PER CENT
FUEL CONSUMPTION PER BARREL RUN TO STILLS
PERCENTAGE YIELD OF GASOLINE FROM CRUDE

FIGURE 26. Indicators of technical progress in the oil and gas industry.

Technological advance in oil and gas production is indicated by the increasing depth of drilling. Several wells are producing at 10,000 feet, one has been drilled to 12,700 feet, and still deeper holes are anticipated. (Data from DeGolyer and others.)

Progress in pipe-line construction is indicated by the increasing radius of transmission of natural gas. This is made possible by stronger pipe, welded joints, increased working pressures and capacity, and reductions in cost of trenching and laying pipe.

Progress in refining is indicated by the increase in yield of gasoline and the declining consumption of fuel per barrel of crude oil refined.

shortage of crude petroleum is definitely in sight it is to be expected that this tendency will be reversed and that the effort will be concentrated on high yields of lubricants.

The basic qualities that control lubricating value are not well understood. It may be said that development in the production and skilled use of lubricants is in its infancy in spite of the hundreds of lubricating compounds, each for a specialized purpose, now available. Solvent refining, a development of recent years, has added greatly to the flexibility with which a desired lubricant can be produced. Increased development and application of this process to a wider range of uses is anticipated.

Recently the demand for furnace oils for domestic heating has swelled to unprecedented proportions. So far as published information will indicate, this demand has found the technologist somewhat unprepared. There appears to be a dearth of studies to determine the most desirable qualities and methods of producing and utilizing these oils.

There have been a multitude of other developments, unimportant to the petroleum industry because of the comparatively small volume of material involved, but highly important in their contribution to the effectiveness and comfort of life. New chemicals are being found, almost from day to day. Some have already found places in industry and promise to become indispensable. Others will displace materials now in use. The hardship on the present purveyors of the displaced materials will be compensated, from a national viewpoint, by the increase of available resources for a given purpose. Others may result in the development of new industries. Some are filling needs not previously met, as, for example, the effective insecticides and fungicides that recently have appeared.

It is encouraging that the most important developments are in the direction of conservation. Thus the polymerization process utilizes raw materials that previously were either wasted or burned under boilers. Cracking makes gasoline out of raw materials that earlier were considered suitable only for fuel. Solvent refining promises to permit the manufacture of valuable lubricants from raw materials previously considered unsuitable.

The record of refinery construction during the past 2 years is evidence of the seriousness with which the refining industry is undertaking to apply recent improvements in technology. In fact technology is responsible in part for the fact that there is today substantially more refinery capacity in the United States than is needed to supply the Nation's needs of refined products. The mere fact that a plant exists does not justify its operation. We are long on refineries, but

we are short on refineries competent to utilize crude petroleum to the best advantage.

There is no apparent prospect of interruption of the trend toward intensive technologic attack on refinery problems with resultant improvement of products now in demand, development of new products, and conversion to higher use of more and more of the available raw material.

Motor Fuel and Lubricants from Other Raw Materials.—Much has been written about the possibility of securing motor fuel and lubricants from substitute raw materials such as coal and oil shale. The development of methods of utilizing these alternative sources is among the most important achievements in the field of mineral technology and has gone far enough to effectively dispel the bogey of a break-down of civilization through failure of the petroleum supply. It is essential to realize, however, that the alternative sources are inherently high-cost, and available—by any techniques now known—only at prices several times what American consumers are accustomed to pay. At present oil shale and coal contribute only an insignificant part of the world's supply of motor fuel and nothing of its lubricants.

Benzol, which is a liquid fuel suitable for use in internal-combustion engines, is recovered as a byproduct in converting coal into high-temperature coke such as is used in the iron and steel industry. At present the world's production of benzol is about 6,000,000 barrels a year, only part of which is available for motor fuel since there is an established demand for other purposes. If the entire world production were utilized as motor fuel it would supply only about 1½ percent of the demand for motor fuel in the United States alone.

There has been a slow development of low-temperature coke plants. By this process half to two-thirds of a barrel of liquid oil can be obtained per ton of coal, and this oil can be converted into motor fuel and fuel oil subject to somewhat more than normal refining losses. The quantity of crude oil produced at the three small plants now operating in the United States is at most a few thousand barrels a year. If all the bituminous coal mined in the United States in 1935 had been subjected to low-temperature carbonization it might have yielded, allowing for refining losses, about 100,000,000 barrels of motor fuel, or about one-fourth of our domestic demand. A market would have to be found for at least 280,000,000 tons of low-temperature coke. The investment in plant would be stupendous. It seems obvious that no substantial supplement to our supply of petroleum from this source will be available during the next 10 years.

Hydrogenation of coal probably has intrigued the lay mind more than any other proposed process for securing motor fuel and lubricants from coal. There is a popular belief that coal can be liquefied, combined with hydrogen, and made to yield any desired type of liquid oil. Actually, although work on this process has been in progress for 23 years since Bergius first announced that he had succeeded in liquefying coal and combining it with hydrogen to produce desirable types of liquid hydrocarbons, there are today less than a half-dozen plants operating on a commercial scale. All of these are maintained by Government aid in countries that have to import most or all of their petroleum requirements. The most intensive development has been in Germany and in England. The actual production of the German works has been less than one and a half million barrels per year, which would be hardly a day's supply for the automobiles of the United States. The total production to date from the English works has been less than 2 million barrels. The cost of this motor fuel is indicated by a statement credited to the head of the German Wintershall Co.[14] to the effect that the cost ratio between imported and home-produced motor fuel was as 7 to 25. In other words, each gallon of motor fuel produced from coal cost somewhat more than three times as much as a gallon of imported motor fuel manufactured from petroleum.

No lubricating oil has been produced from coal on a commercial scale so far as the writer can learn.

Alcohol can be used as a fuel in internal-combustion engines, and many nations, under the pressure of interested groups or of the desire to develop a domestic supply of fuel for their automobiles, have passed laws requiring a certain amount of alcohol to be mixed with all gasoline used in automobiles. The result has been to greatly increase either the direct or the indirect cost of motor fuel. Experience to date indicates that if we had to rely exclusively on alcohol produced by methods now prevalent in European countries, the cost of motor fuel would be increased by 300 to 1,000 percent.

However, since alcohol is a serviceable fuel, we may anticipate the development of processes that will decrease the cost of producing alcohol and it will probably be used to supplement gasoline should the need arise.

Oil shale is a third possible source of synthetic motor fuel. In the United States alone there is more potential motor fuel in oil shale than will ever be produced from the oil fields of this country. However, only so much is commercially available as can be produced at a cost that will justify its use. At the

[14] Germany's Synthetic Motor Fuel Production, Petroleum Times, May 16, 1936.

moment this amounts to zero. The status of oil shale was admirably described by Gavin,[15] who said:

> It is hardly believed that shale oil, considered in a large way, will be a competitor of petroleum; it is more likely to be a slowly developed successor of petroleum.
>
> The writer believes that the oil shale industry will ultimately be an industry of great magnitude and commercial importance in this country, but many years and much money will be required before it reaches this status. In its last analysis, it is an industry comparable with the low-grade-ore mining industries of the Western States and, like them, will require the services of the highest types of business, executive and technical skill, backed by large capital, and which can afford and be prepared to wait a considerable time for a conservative return on the investment.

Although the above was written 12 years ago, it applies with equal force today. It is not anticipated that the production of shale oil will become an important industry in the United States during the present generation.

In Europe an appreciable number of large motor vehicles—buses and trucks—are driven by gasogenes. These are appliances, carried on the vehicle, which distil woody or coaly material and produce gas which is consumed in the motor.

From the economic standpoint these appliances may justify themselves in regions where cost of gasoline is great and cost of wood or charcoal or lignite is low, but in general the cost and the problems of providing adequate and convenient fuel supply and of disposing of waste appear to preclude any possibility of general adoption of these devices.

The preceding discussion has dealt exclusively with motor fuels. It is seen that substitutes are obtainable at a price. This is not yet true of lubricants. Satisfactory lubricants can probably be manufactured from shale oil, but this has not been demonstrated. Excellent lubricants for certain purposes can be manufactured from certain vegetable oils, and in particular from castor oil, but a new technology must be developed before the lubricating needs of the world can be supplied from any raw material other than petroleum. Looking back over the road already traversed in cracking the large petroleum molecule into smaller ones, and now in recombining smaller molecules into larger by the process of polymerization, it does not seem impossible that when necessity requires the trick can be done.

The United States possesses huge reserves of coal and of oil shale, the two most promising substitute raw materials. It also has a supply of petroleum adequate to meet its needs for many years to come. Other nations, lacking petroleum resources and driven by nationalistic zeal, are intensively at work on processes to develop petroleum substitutes from coal and shale. If they succeed in so reducing costs as to compete successfully with oil from natural reservoirs, the processes developed will doubtless become generally available. In any event, if and when the need arises to replace petroleum products with liquid hydrocarbons from coal and oil shale, the United States will have the benefits of this pioneer work which will, by so much, shorten the task of our own technologists.

This does not mean that the technology of securing petroleum substitutes from coal and oil shale should be ignored in this country. On the contrary, our technologists should not only keep abreast of what is being done abroad but should themselves give thought and effort to these problems. This is actually being done in the laboratories of the Bureau of Mines and at least some of the major oil companies of this country and is obviously a fertile field for research by the producers of coal.

Looking ahead, we may anticipate no great industrial development of petroleum substitutes in this country during the next 10 years, but may expect a steady increase of experimental and semi-commercial work looking toward the utilization of substitute materials when economic conditions warrant. The increase in cost which the substitutes imply reinforces the case for conserving our supplies of petroleum by avoidance of preventable waste.

Nonmetallic Materials[16]

Lack of space prevents more than a passing reference to the technical changes at work in the great group of nonmetallic raw materials, which rank close to the better-known metals in point of value. Figure 23 suggests that the nonmetallics, as exemplified by sulphur, gypsum, and phosphate, have shown an increase in output per worker equalling or surpassing the metals and fuels. In the case of sulphur the increase is partly due to the discovery of new deposits but chiefly to new methods. Largely on account of these advances in efficiency total employment in the nonmetallic industries was lower during the 1920's than in 1912, despite the post-war activity in construction.

Among the technical advances which have contributed to increasing productivity within this group are the unique Frasch process for mining sulphur by drilling wells, injecting hot water into the deposit, melting out the sulphur and forcing it to the surface; the wire saw, introduced in the slate quarries in 1926, and now spreading to the production of building stone; the sand-blast process of carving; better equipment

[15] Gavin, M. J. Oil Shale, A Historical, Technical, and Economic Study, Bureau of Mines Bull. 210, 1924.

[16] By Oliver Bowles, Chief Engineer, Building Materials Section, U. S. Bureau of Mines.

for the handling of bulk material; improvements in crushing and grinding machinery; larger and more efficient cement and lime kilns; and remarkable savings in fuel consumption. (See fig. 27.[17])

Many industries of this group quarry broken rock and have profited from the increase in size and flexibility of power shovels already referred to in connection with coal mining. Related economies include the development of improved explosives (liquid oxygen for the largest scale work), and the use of churn drills to prepare 6-inch shot holes perhaps 100 feet deep, which permit blasting down a whole face at once. At the same time, the mining of stone by underground methods has been improved and extended, where special-quality material not available at the surface is desired. In the related industry of sand and gravel a very great increase in output per man-hour has occurred, centering around the use of labor-saving machinery.

Like other mineral industries, the nonmetallics have shown a trend toward concentration of business in larger plants. In lime, cement, and crushed stone, for example, the trend toward larger units is outstanding. (See figs. 27 and 32.) An exception to this general tendency is the portable crushed stone or sand and gravel plant, which can be shifted from one location to another. The portables draw their raw material from local roadside pits, and by savings in freight they are competing successfully against the larger centralized plants tied to a fixed location.

Further economies in production costs are expected by mechanical improvements along the lines already indicated. Attention is also being centered on raising the quality of the product, and on recovering byproducts from material formerly wasted. One development that will bear watching is the extraction of carbon dioxide from the spent gases of lime and cement kilns and its compression into "dry ice." This is already practiced at one or two plants.

Perhaps the most significant change is the introduction of froth flotation in the treatment of nonmetallic materials in a finely divided state. The revolutionary effects of this process upon metal mining are discussed elsewhere (p. 166). Recently it has been applied to the recovery of rock phosphate, with a saving of a large fraction of the crude rock which was formerly wasted in the tailings. In some cases flotation is said to double the recovery. Flotation is also being used by a portland cement mill to purify limestone which would otherwise not yield a satisfactory cement, and it has been applied practically or experimentally to other nonmetallics. Enough has been done to suggest that in this field, as previously in metal mining, flotation may have very great effects in improving quality, reducing waste, and making available low-grade deposits formerly considered of no value.

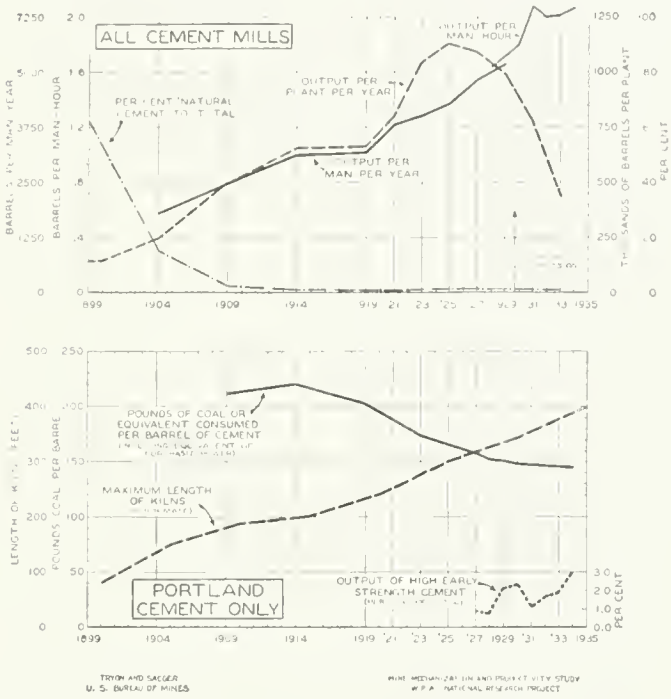

FIGURE 27. Indicators of technical progress in nonmetallic industries as illustrated by cement, 1899–1935.

The cement industry is the largest, in terms of value, of the great nonmetallic group, and it has shown a rate of technical advance equalling or exceeding that in most other lines of industry.

The increase in size of plant is indicated by the average output per plant, which rose from 145,000 barrels in 1899 to about 1,000,000 barrels in 1929 (the apparent decrease thereafter being due to the great depression).

Output per man-year increased very rapidly down to 1929. The more accurate record of output per man-hour, which begins in 1928, shows a further increase during the depression.

At the same time the quality of the product has improved, as indicated, for example, by the virtual elimination of "natural" cement and its replacement by portland cement. Recent years have also seen the introduction of greatly improved portlands, such as high early strength cements.

Increasing efficiency is further indicated by the remarkable savings in fuel required per barrel of product. This is associated with a number of technical improvements, one of which is the increasing length of kilns.

The Major Metals[18]

Group Relations

Iron, copper, lead, and zinc are ranked by everyone as major metals, each having a distinct industry for its production, reduction, refining, and fabrica-

[17] The data in fig. 27 are derived as follows:

Output per plant per year and per man per year computed from the Census of Manufactures. Output per man-hour from H. H. Hughes, B. W. Bagley, and E. T. Shuey, Cement, U. S. Bureau of Mines Minerals Yearbook 1935, p. 894. Percent natural cement to total and output of high-early-strength cement also from Bureau of Mines annual reports. Pounds of coal or equivalent consumed per barrel of cement from F. G. Tryon and H. O. Rogers, Statistical Studies of Progress in Fuel Efficiency, Transactions, Second World Power Conference, vol. VI, p. 244, Berlin, 1930, continued by N. Yaworski.

[18] By T. T. Read, Vinton Professor of Mining, Columbia University. During Professor Read's absence in China, he has entrusted to Mr. Tryon the responsibility of cutting and rearranging his original manuscript to meet the limitations of space and the contributions of other authors.

tion into articles of common use. Aluminum is less surely a member of the group. Gold and silver would not ordinarily be regarded as major metals, but they may well be included in this discussion since their social significance is much greater than their technologic importance, and also because they are to so material a degree byproducts of copper and lead production that they exert considerable influence upon those industries.

The production of the major metals from domestic sources depends on the existence of suitable deposits and on complex interrelationships with other factors. Since it is clearly impracticable to discuss all these factors simultaneously, it seems best to first consider the technology of mining proper, the delivery on the surface of material originally underground; then the mechanical concentration of such material preliminary to smelting; and finally the chemical operation of smelting and refining. But it must be kept in mind that each of these operations is dependent on the others, and any one of them may exert a governing influence.

Mining of Metallic Ores

Open-pit Mining.—The proportion of the total output produced by surface or open-pit mining has been increasing in recent years (fig. 28) and this may be regarded as a highly probable trend in the years immediately ahead. As pointed out in connection with

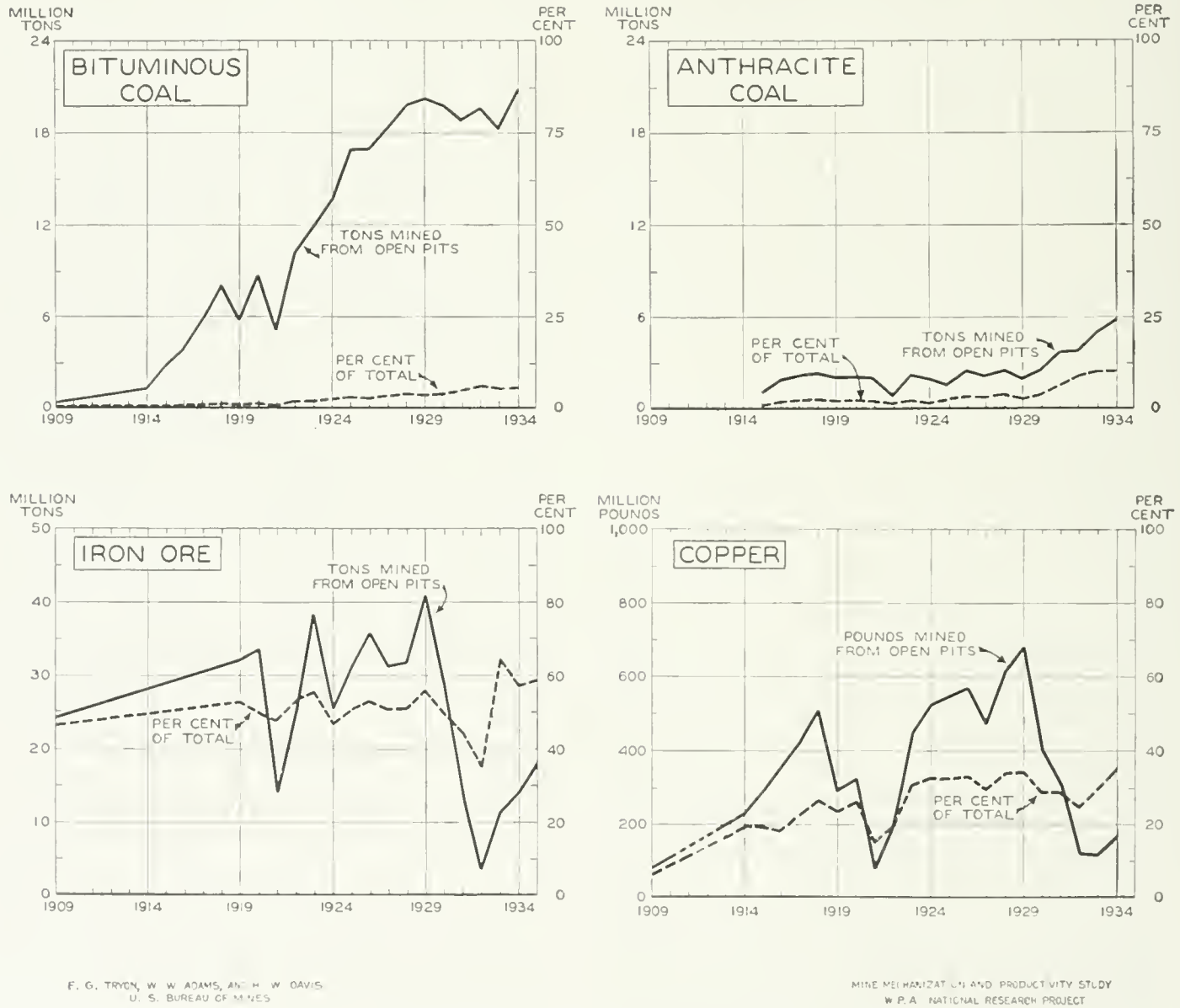

FIGURE 28. Rise of open-cut or strip mining in coal, iron, and copper.

An outstanding technological trend, affecting both coal and metal mining, is the rise of open-pit, or strip, mining with power shovels. Despite the exhaustion of some of the ground more easily available for stripping, an increase in the size and range of power shovels and other improvements is causing an expansion in relation to underground mining.

coal mining the increasing depths to which strip mining has been carried have not resulted from revolutionary inventions, but rather from the evolution of the power shovel and associated machinery, and the progressive finding of better solutions for such mechanical problems as the starting and stopping of the swing of a heavy dipper, to cite one example.

On the other hand, the present trend toward open-pit mining is clearly one that, except perhaps in the case of iron ore, must eventually slacken and reverse, because with the progressive exhaustion of bodies that lie at or near the surface, underground mining becomes a necessity. Iron ore is excepted because the resources that lie near the surface are very large and it may be cheaper to bring surface-mined ore from a great distance than to seek to obtain it locally at greater depths. But no considerable amounts of lead or zinc are obtained by surface mining at present, and nearly all the copper deposits of present commercial grade to which surface mining seems applicable are already being attacked in that way.

Depth in Relation to Grade of Ore.—Even the deepest of underground mining must be regarded as shallow mining, when one reflects that the mile and a half below the surface to which metal-mining operations have penetrated represents less than one-half of 1 percent of the total distance to the center of the earth. The fear of a shortage of available ore deposits thus may appear chimerical, but it has some substantial basis. The ore deposits now being mined at 8,000 feet have persisted to that depth from their original discovery on the surface. Since the majority of deposits traced downward from the surface are found to terminate at lesser depths, mining at great depths will typically involve the finding of deposits which do not extend to the surface. This in itself will be an expensive task. Furthermore, working at increasing depths involves a progressive increase in operating costs, and the best that can well be hoped from improved technology is that it will slacken the rate of increase.

It will be suggested that the more obvious solution of these difficulties is that deposits worked at great depths must be of higher grade or unit value. Copper ore has recently (1925–29) been mined underground at a depth of less than 1,000 feet at a production cost of 40 cents per ton,[19] or a little more than 3 cents per pound of copper obtained from it. A 10 percent copper ore could, on the same basis, bear a production cost of $6 per ton, and such an ore could be worked at very great depths. Ores of so high a grade, however, are hard to find. The average content of copper ore mined in the United States 1924–33 was 1.49 percent and the highest grade ore produced in any considerable quantity in 1933 was about 600,000 tons in Arizona, averaging 7¾ percent copper content, and corresponding to less than one-fifth of the total domestic output for that year. The easy inference that the way to meet increased mining costs is to find higher-grade ore bodies seems further blocked by the geological fact that most ore bodies tend to decrease rather than increase in grade with depth. In the case of iron ore, moreover, the grade of ore already mined is nearly as good as can theoretically be hoped for, since it approximates pure iron oxide. Finally, one must reckon with the fact that rich ore does not commonly occur in large bodies. The large-scale copper-mining enterprises that achieve low costs are with few exceptions working on low-grade deposits.

There seems, therefore, little escape from the prospect that metal mining in the future must adjust itself to greater depths or lower grade ores, or even to both. In the case of iron ore, such readjustments in the near future are not likely to be more than preliminary steps. The Lake Superior district, which now furnishes four-fifths of our iron, has reserves in ore of present commercial grade sufficient to supply the anticipated demand upon the district for about 40 years. Alabama, the next largest district, has reserves to meet the anticipated Southern demand for about 300 years. Copper reserves in ore of present commercial grade are sufficient for 40 years at the 10-year average of demand. Those of lead and zinc, on the other hand, are only half as great, or say a 20 years' supply in ores of present standards.[20] It is in the case of lead and zinc, therefore, that we should expect to perceive the earliest developments of general trends in mining techniques to meet the changing conditions forecast by depletion.

Mechanization and Mining Methods Underground.—What these trends are likely to be can only be inferred from past experience. An outstanding feature of that experience has been the rise in wage rates and the increase in output per worker, shown in figure 23, made possible by the introduction of labor-saving devices. The relation between the wage rate and mechanization is reciprocal. The general increase in wage levels over the last generation when prices of the metals were declining (fig. 22) has stimulated mechanization, and mechanization in turn has aided the payment of higher wages. As the long-time trend of wage scales appears to be upward, metal mining technology is likely to continue to be called on to adjust itself to advancing levels of wage.

[19] Trans. Am. Inst. Min. and Met. Eng., 1930, p. 41.

[20] Leith, Kenneth and Liddell, Donald M. The Mineral Reserves of the United States and Its Capacity for Production, National Resources Committee, Mar. 1936, pp. 98–100, 55, 124, 231.

Increasing production per man-hour of labor through supplementing human efforts by mechanical power and devices for its more effective application involves complex problems that have already been mentioned in the consideration of coal mining and need not be repeated here, except to allude to significant differences. In coal mining all the deposit is removed, unless part of it is left to support the surface, but in copper, lead, and zinc mining the deposits are more irregular; and in most cases instead of mining the whole deposit only those parts rich enough to bear the cost of removal are taken out. This presents little difficulty where mining is done largely by hand labor, but segregating that which is not desired from that which is sought raises difficulties in almost every technique which seeks to increase output per man-hour through mechanization.

The actual procedure of producing mineral may be divided into breaking the solid mass into fragments suitable for handling, loading the broken material into cars for transport, transporting it horizontally and hoisting it vertically. Where conditions permit, the two latter operations may be combined into a single movement on an incline. The trends in the latter two are so evident as to need little comment. In common with all transportation they involve larger cars, longer trains, and higher speeds of movement; likewise they seem to have already nearly attained the practicable and economic limits of development.

Increase of output per man-hour of labor in loading presents alternatives. Either mechanical loading may be substituted for hand shoveling or mining operations may be so planned as to draw the broken material out of chambers and passages above directly into the cars. The first has already been discussed under coal mining and has made substantial progress in some branches of metal mining; the second is not practicable in deposits of no great thickness and of slight dip, such as coal seams. But in many deposits of metallic ore it is feasible to drive haulageways beneath the deposit and draw the ore down into them. In some cases the physical nature of the deposit is such that it is practicable to "block-cave"; that is, undercut the deposit and allow it to fall down from above as it is removed beneath. This is the procedure in the method cited on page 58 which has resulted in the lowest mining costs yet attained underground.[21]

One unfamiliar with mining will naturally ask why such a process should not at once become standard procedure, but every miner realizes that the conditions which permit its application are unfortunately rather exceptional. Only a limited proportion of our total mineral is now, or is ever likely to be, mined in this way, because of the limitation. (On the other hand, when mineral occurs in deposits that are so small and irregular that the minimum cost of mining is, say $15 per ton, they will still be mined if the mineral itself is worth more than $15 per ton. Large-scale mechanized mining will never drive out high-cost, small-scale hand mining so long as there are high-grade deposits that can only be mined by these latter methods.) It may prove true that increase in production per man-hour of labor has already reached its highest expression, and that the metal supplies of the future will be obtained at a greater expenditure of human effort.

Mechanical effort will also be increased, the increased mechanical work required in hoisting ore from greater depths being obvious. This is not the critical factor, however, for it is common practice in mining to drop broken ore several hundred feet before beginning to hoist it, merely to facilitate its handling underground. Ore can be successfully, and not too expensively, hoisted from depths two or three times as great as the present average for the United States, the problem is merely to find the best way of doing it at an individual property. With rare exception, the handling of water will not increase costs in deep mining, since deep mines, for reasons that are well understood by geologists, tend to be dry.

In the breaking of ore to permit its removal—as distinct from the task of loading—no revolutionary developments need be expected, for the technique now used ranges from drilling and blasting all the ore to undercutting it and allowing it to fall by itself without blasting. The range of cost is about the same for either, this odd result deriving from the fact that when ore "caves" many of the blocks are too large for handling and the cost of blasting or otherwise breaking them is such that it is just as cheap to blast all the ore, if it can be done on a sufficiently large scale. The cost of drilling holes, loading them with explosive and firing the blast has already been reduced to where relatively little margin exists for further improvement.

Special Problems of Deep Mining.—On the other hand, there are difficulties and problems peculiar to increased depth. They center around the high temperatures encountered, and the increasing pressures, which make the maintenance of any opening progressively more difficult.

It is now generally understood that a working man must be cooled, just as any internal-combustion engine must be cooled if it is to function efficiently. If the air surrounding a man is at his normal body temperature this cooling action ceases unless the air is dry enough so he can be cooled by the evaporation of perspiration. When air passes down into a mine it tends to take up moisture from contact with wet walls, and

[21] Production at the mine cited was 27 tons per man-day. The highest attained in coal mining is 15 tons per man per 7-hour day, and the average for coal production in the United States is 5 tons per man per day.

also to warm up, from compression, one degree for every 200 feet of descent. In addition, the temperature of the rock increases as one goes deeper into the ground; the rate varies at different places, but may amount to as much as 40° in 5,000 feet. The result of all these factors is that, in most regions at a depth of 8,000 feet or more, the temperature and humidity in the working places are likely to be so high that no effective work is possible. The "cooling power" of the air must be increased, for no amount of air movement will do any good if it has no cooling power. Much study has been given to this problem in recent years. In the metal mines, for example, adoption of better ventilation has greatly improved conditions, and for the depths at which we are at present working in the United States fairly satisfactory solutions have been attained. The next step is cooling the air by artificial refrigeration. Equipment of this character has been installed in two of the world's deepest mines, the St. John del Rey of Brazil (8,100 feet deep) and the Robinson Deep of South Africa (8,500 feet). Success of these installations may lower the effective depth at which mining can be carried on. How much deeper they, or more effective methods, may permit men to go, no one can predict. The problem is by no means easy.

Since it is difficult to maintain conditions at which men can work efficiently at great depths, the logical inference is to try to develop methods that will utilize mechanical power to the maximum and require a minimum of human effort. But this leads to a conflict, because the power devices commonly used are usually electrically operated and electrical machinery typically develops heat, thus tending to make an already bad situation worse. In recent years the trend has been away from the use of compressed air machinery underground, except for drilling in which it is standard practice, but it may prove desirable to reverse this trend and use compressed air much more extensively than has been the practice. Discussion of the technological problems involved would require too much space, and not be of general interest while the developments are still in such an embryonic stage that it is difficult to predict what direction they may take. Nor will it make much difference to the general public how deep mining is done, so long as it can be done successfully.

The pressure that exists in the earth at great depth constitutes another major problem in deep mining. The practical problems of protecting the miners from the fall of overlying material that is locally too weak to hold up are discussed in connection with safety and here we need only refer to the special problem that arises in all kinds of mines when the depth becomes very great, with a corresponding increase in the stresses existing in the rocks. Not only do fragments fall from the roof but the bottom heaves up and the sides burst out, much as a nutshell flies about when it is cracked in a nutcracker. Meeting this condition is hampered by a lack of knowledge of all the factors involved, since the early attempts at meeting it were made by "practical" men. Beyond venturing that the solution will be attained through the correct application of mechanical and structural principles, and a feeling of some confidence that a solution can eventually be found that will permit mining at substantially greater depths, it is not possible to make definite statements regarding it at this time. Fortunately but few mines except those of gold have yet attained depths where this problem becomes very important. The gold mines of South Africa will probably serve as an experimental laboratory in mining at depth with the advantage that the Union Government, through control of the South African pound, can fix the price of gold in terms of local goods and services at such level as may be necessary to permit its major industry to continue in the face of increasing difficulties.

The natural thought that the great pressures existing in depths can be utilized to cause the rock to break itself, and the broken rock drawn off in cars, leaving only lateral and vertical transportation as the remaining operations to be handled with as little manpower as possible, overlooks the requirement of such a method of attack for the opening and maintenance for years of passageways beneath the ore-body. And such an operation largely tends to substitute men who control the operations for miners who actually dig and shovel the ore. Even in a mine where all the ore is "caved" the output per man per day does not rise much about 25 tons. "Completely mechanized" mining still requires much human supervision and control.

A recent development by which 5-foot shafts have been bored instead of sunk in the usual manner indicates that shafts can in the future be sunk more cheaply, possibly reducing the cost, at great depths, to one-third of what is now regarded as normal. This will, of course, greatly promote exploitation at depth, since a deep shaft might easily cost $500,000.

Outlook for Mining Costs.—The general conclusion that appears from our analysis of the trends of metal mining is that there is no reason to imagine that any ore will be mined in the future much more cheaply than some of it is now. Savings will certainly continue from the more general adoption of methods and machinery already developed in the most successful mines, and new technical advances will doubtless occur. But it seems equally clear that the long run

trend will be toward increasing natural handicaps and toward higher wage rates. A dilemma often faced will be whether to produce ore from a greater depth or bring it from greater distance.

Ore Dressing or Concentration

Another solution of the growing difficulties of mining is the use of techniques which produce ore of lower grade at a decreased cost, as compared with continuing to produce ore of standard grade at increased cost. The needed quantities of copper, lead, and zinc have long been obtained by producing rather low-grade ores, as the figures cited for copper indicate. What is taken out of the ground and brought to the surface is, except in the case of petroleum, coal, and iron, not relatively pure mineral but mineral of the kinds desired mixed with waste. A 1-pound lump of ore is typically an intimate mixture of particles of the desired mineral with others that are of no use: the problem is to separate the particles desired from the others. Only in the case of gold "placers" are the particles already separate: typically they are adherent, and must be broken apart. This is more difficult than removing a nut from its shell, since breaking a lump which is half mineral and half waste will not necessarily produce small particles that are either mineral or waste; they may still be half mineral and half waste. If the particles of mineral are only $\frac{1}{100}$ inch in diameter, a $\frac{1}{10}$-inch lump will still be a mixture; whenever the desired mineral exists in small particles, it cannot be separated without fine crushing.

Until recent years this condition resulted in a stalemate, for the mechanical processes used to separate a mineral from waste were effective only on particles of appreciable size. If the individual particles were small they could not be separated; unless they were small they were still a mixture of mineral and waste.

But since 1900, a new technique called froth flotation has been developed. In this process, a pulp of finely ground ore and water is mixed with relatively minute quantities of one or more chemical agents. The mixture is then made to froth either by mechanical agitation or by blowing into it a stream of air. The particles of mineral stick to the air bubbles and are floated to the top, to be scraped off or otherwise collected, while the waste particles remain below as tailing. The physics and chemistry of floation are still not fully understood, but in the separation of small particles the process is a revolutionary advance. In fact, the particles cannot be too small to be saved in this way. Flotation has the additional advantage that it permits an easy and effective (usually) separation of minerals that could not previously be separated in any size, because they have nearly the same specific gravity. This results in changes in concentrating and smelting procedure that may best be illustrated by a specific example.

The ore in a given mine consists of an intimate mixture of copper, lead, zinc, and iron minerals, plus gold and silver. By the older technique perhaps only two-thirds of the total amounts of these minerals present could be saved in the concentrate. Furthermore the zinc and iron minerals could not be separated from the lead, consequently they were allowed to go with it to the final stage of smelting in which they were not only lost, but perhaps somewhat increased the cost of the lead-smelting operation. Froth flotation now permits the production of a clean copper mineral product, a clean lead mineral product, a zinc product, and iron mineral that perhaps may be sold for acid making. The total saving may thus perhaps be pushed up to over 90 percent of the valuable minerals present in the ore, and, in addition, the higher metal content of the product, plus its freedom from undesirable constituents, greatly reduces the cost of the smelting. The business aspects of this are quite clear. If the cost of mining the ore in this mine is $2.50 per ton and only one-third of the total ore is of high enough grade so that the margin left after paying concentration, transportation, and smelting charges exceeds $2.50, only that portion of the total ore can be mined. But suppose these charges can be reduced 50 cents per ton, they will permit ore which is worth 50 cents less per ton to be mined, and possibly, through simplifying the mining operations, lower their cost. All the ore can perhaps then be mined, possibly at a greater profit per ton than would accrue from mining the higher-grade ore. Many mines that could not be operated at all before the advent of froth flotation have been turned by it into profitable producers.

The invention of flotation has proved to be among the most important developments in the history of metal-mining technology. It is one of the main factors that has made possible the working of low-grade ores. Thirty-five years ago, a 2-percent copper ore had no value. Today, some of the most profitable mines work ores of 1 percent. The change has added many million tons to the national ore reserves and directed the industry of copper mining to new centers of activity. In 1930, over 44 percent of the copper output came from the so-called porphyry mines, working deposits that were known in 1900 but considered then as valueless. Meanwhile, the price of copper had declined from 17 cents to 13 cents a pound. Similar changes have lowered the economic limits of working in the ores of lead and zinc, gold and silver, and some of the lesser metals.[22] In large part, the change is

[22] Tryon, F. G. The Changing Distribution of Resources, in Migration and Economic Opportunity, University of Pennsylvania Press, Philadelphia, 1936.

due to the introduction of the mass methods of mining with power shovels in open pits or with caving systems underground, already discussed, but in part also it is due to the advances in concentration methods of which flotation is the chief. The increasing recovery of the metal present in the ore and the increasing purity of the concentrates obtained are illustrated in figure 29.[23]

The question immediately arises as to what further developments along this line may be hoped for. Can districts in which the reserves of minable ore, under present conditions, are fairly well known expect to have their life greatly prolonged by further reductions in treatment costs that will permit the mining of lower-grade ores? No sweeping statement can be made as to this, because the ore in an individual deposit may be nearly all of the same grade, with a sharp distinction between ore and that which is not ore, while in other cases it may shade gradually out into barren rock. In the latter case, large reserves of low-grade ore may exist and further reductions in concentration and smelting costs may either extend its production life or perhaps permit an increase in current operations from, say, 1,000 tons daily to 2,000 tons daily. What are the possibilities for such reductions where low-grade reserves exist?

In the case of froth flotation they seem to be limited to those general improvements common to all industrial processes. The two largest factors in the cost of flotation concentration are crushing and reagents. Both the chemistry and physics of the flotation process are as yet incompletely understood and some reduction in the cost of reagents may be possible, though the recent trend has been rather toward the use of more expensive reagents wherever they would produce a corresponding increase in saving or improvement of the product. Grinding, the crushing operation necessary to produce the fine particles essential for froth flotation, offers less promise, since it is difficult to keep grinding surfaces from coming into contact and thus destroying each other, while some ores are so hard that the abrading action tends to become mutual. In any case the power input required to reduce a ¼-inch particle to a corresponding number of 1/100-inch particles is surprisingly large, with no hint yet as to how it could be reduced. Except for grinding the cost of froth flotation is already so low that the margin for reduction is small. The present trend of research is toward making separations not now possible or further perfecting of those being made. Where a saving of 90 percent is already being made, a further increase by 5 percent may be extremely important, since it may mean the difference between a satisfactory profit and none at all, but except where it means making available ore supplies that were submarginal, it makes no great additions to existing recoveries.

FIGURE 29. Technologic advances in ore dressing or concentration.

Introduction of froth flotation after 1914, along with other improvements, increased the recovery of the copper present in the ore from 65 or 75 percent to 90 or 95 percent, despite a general decline in the grade of ore treated. (At the Calumet and Hecla mill flotation was applied only to the fine material known as slimes, and part of the improvement shown is due to leaching of sands and other advances.)

At the same time, a somewhat richer concentrate was produced which facilitated the subsequent task of smelting.

The improvement known as selective flotation, introduced about 1921, permitted increased effectiveness in separation of different metals from complex ores. This enabled recovery of substantial amounts of metals formerly lost through inability to separate them. It is illustrated by the trend in content of zinc concentrates.

These technical changes and related improvements in grinding are among the most important factors making possible the working of low-grade ones.

(Data on copper concentration from T. G. Chapman, U. S. Bureau of Mines Bull. 392; those on zinc concentrates from W. R. Ingalls, American Bureau of Metal Statistics.)

Smelting and Refining

Concentration processes make no change in the mineral mined; they merely separate mixtures of minerals into nearly pure products. A final smelting process is necessary to convert the mineral into metal. In the actual business of producing the metals, smelting is often integrated with mining, so that when one speaks

[23] The data in fig. 29 are derived as follows: Percentage of recovery at Calumet and Hecla mill and Utah Copper mill from T. G. Chapman, Concentration of Copper Ores in North America, U. S. Bureau of Mines, Bull. 392, p. 11. Percent of zinc and lead in zinc concentrates from W. R. Ingalls, Yearbook, American Bureau of Metal Statistics.

of the lead industry or the copper industry he necessarily includes the operation of smelting and the final stage of refining.

At this point mineral technology grades off into that special form of chemistry known as process metallurgy, for smelting and refining are commonly chemical reactions conducted on a gigantic scale. Process metallurgy, in turn, is closely related to physical metallurgy, which deals with the improvement of the crude ingot metal by subsequent heat treatment or by mixture with other metals to form alloys. The trends of both physical and process metallurgy are the subject of another chapter, which spares us the task of tracing them here.

All that need be done now is to point out that the progress of smelting has contributed greatly to making the metals cheaper and more abundant. Among the lines of advance developed in the later chapter are increasing purity of product, recovery of an increasing percentage of the metal in the ore, extraordinary savings in fuel per pound of metal produced, savings in labor through mechanization, and recovery of byproducts formerly wasted. The savings effected in these ways have gone far to offset the increasing handicaps of mineral depletion and to make possible the profitable treatment of low-grade ores.

One line of development requires special mention. Partly through improvement of the familiar processes of fire metallurgy and partly through the development of electrolytic processes, there is a growing ability to treat complex ores containing several metals and to successfully separate them. This development makes available large tonnages of ores that formerly were considered unprofitable. To the generalizations that the metal supplies of the future will tend to come from greater depths and from lower-grade ores, we can therefore add a third one that they will also tend to come from more complex mixtures.

Trend in Number and Size of Mines

The long-time trend in the metals, as in the case of coal, is toward fewer and larger enterprises. Unemployment and devaluation of the dollar have brought on a picturesque revival of small-scale gold mining but this seems an exception. Otherwise, the trend toward larger units is apparent in all three of the major departments—mining, concentrating, and smelting,[24] and most of the technical changes we have outlined work to favor large-scale operation.

There is, however, one factor to be mentioned that encourages the smaller mine. It results from the mine's relations to the concentrator and smelter. For the efficient and economical operation of a reduction plant, it should be fed with raw material of unvarying quality, since it is required to make a product of uniform, or nearly uniform, quality. But no two shovelfuls of ore as removed from a mine are exactly alike. Iron ores are analyzed as mined and then handled in such a way during transport to the blast furnaces that they become mixed to a practicable degree of uniformity. Copper, lead, and zinc ores are much more variable as mined and when rich enough to be sent directly to a smelter, give rise to much difficulty that is normally met by spreading them in layers and by mixing the layers as they later are picked up for delivery to the furnaces.

But where the ore goes first to a concentrating plant the variations in the hour-to-hour output of the mine may create much difficulty in adjusting the concentrating process so as to yield a high recovery and a uniform product. At a large mine, underground control may be exercised to produce more uniformity in the hourly average of material hoisted, but in a small mine this is less practicable. With a small mine, therefore, it may be better to ship the ore to a central concentrating plant which, by mixing the ores as received, may assure itself of more uniform raw material. Within the limits imposed by transportation costs we may expect a trend toward centralization of concentration, paralleling that which has long existed in the centralization of smelting. This in turn may react to permit the operation of small mines which not only could not bear the investment cost of a separate concentration plant, but could not operate it successfully.

Insofar as central concentrating mills do promote the activity of small mines, the result may be considered wholesome. The small mine serves a useful purpose in national metal production in developing little-known prospects to a stage where larger-scale operation is feasible. The normal course of development is the finding of a small amount of mineral which seems to justify doing a little work to ascertain whether there is more. If the results of this are favorable, further expenditure is warranted until eventually there is enough evidence to justify installing large-scale equipment.

This tendency can hardly be expected to offset in full the underlying drift toward large-scale operation which is disclosed, for example, in figure 32. The long-run tendency is clearly toward a decreasing number of larger enterprises.

Outlook for Metal Mining

Our review of the technologic trends in production of the major metals has disclosed some tendencies already observed in the analysis of coal mining—a tendency toward fewer and larger enterprises and a

[24] Tryon, F. G., Concentration and Scatter in the Mineral Industries, Study of Population Redistribution Bull. No. 4, University of Pennsylvania Press, Philadelphia (in preparation).

tendency to substitute mechanical power for human labor. The latter is stimulated by the long-run upward trend of wage rates and results in a gradual change in the kind of skills required. The possibility of actual job displacement depends also upon the uncertain factor of demand, and the outlook for recovery of demand is perhaps more favorable in the case of the metal group than it is in coal.

In some degree, the technologic developments in progress will lead to a reduction in operating costs and so in prices, but in the main they will be attempts to combat rising costs due not only to the factor mentioned, but also to the necessity of utilizing lower-grade, more complex, and deeper-lying ores. Insofar as these attempts are successful they will increase the available reserves. Exhaustion in some regions and expansion in others are to be expected, involving stranded communities and currents of population shift. No sweeping changes in the general pattern of metal-mining enterprise are anticipated, but rather gradual growth and readjustment along the lines indicated.

The Lesser Mineral Industries [25]

Strategic Minerals

The term "strategic minerals" came into use during the World War to designate a variety of mineral substances of which our requirements, previous to the war, had been wholly or largely supplied by imports from abroad. Under war conditions greatly increased amounts of some of these materials were required, imports were sometimes curtailed, and the maintenance of the supply became a major problem of military strategy. With the rise of economic nationalism since 1929 the current interest has shifted from military to political and commercial conflict, but the general conditions remain essentially unchanged and assurance of supplies in an emergency is not the least problem in national defense.

There is no definite list of strategic minerals. Each country has a different set, although nearly everyone would agree as to which the principal ones are for the United States. At present the American list includes manganese, essential for making open-hearth steel; tin, for food containers and bearings; mercury for detonators; tungsten for high-speed tool steels and electric light filaments; chrome ore for tanning, chemical manufacture, refractories, and metallurgy; graphite for crucibles; mica for insulators; platinum for chemical industry; asbestos for heat-resisting uses; nickel for alloy steels and plating—to mention only a few of the more critical uses of these materials.

The strategic minerals fall into two general categories: Minerals which have to possess definite physical or chemical qualities as mined in order to be acceptable, and ores from which it is commercially practicable to recover desired metals. A good example of the first category is graphite. The substance itself occurs rather abundantly in the United States, but in such form that it is only practicable to produce here the quality known in the trade as "amorphous" graphite; for our supply of "chip" and "flake" graphite we were before the war almost wholly dependent on Ceylon. There is no possible way to convert amorphous into flake graphite, and where the latter is necessary it must be obtained from the natural deposits. Mica and asbestos are two other minerals used in their natural form that must be produced in the quality desired. For some uses the domestic quality will suffice; for others the commercial demand is for qualities which as yet can only be obtained from foreign deposits. This list could be greatly extended, but the examples cited must suffice to indicate the problem.

In the second group the emphasis is on metallic content or freedom from impurities, the buyers having set standards of quality, with penalties for failure to meet them that often make it impossible to sell low-grade material. On chromium ores, for example, the standard is 50 percent chromic oxide on ores used for making ferro-chromium, with a penalty for lower content. For making refractories 40 percent chromic oxide is acceptable, below 38 percent may be rejected. Similarly, manganese ore must contain over 45 percent manganese and should be low in silica and iron. The reason why such materials are imported is either because the grade desired cannot be produced here at all or else only at a cost too high to meet the delivered price on imported material.

Examples of materials which apparently cannot be produced in this country are tin, nickel, and platinum. Much attention has been given to the various places in the United States where these are known to occur, and the concensus is that we will probably never be able to supply our needs of these metals from domestic sources, unless indeed geophysical prospecting discloses deposits now wholly unsuspected. Complete certainty is impossible, as is illustrated by potash. Much study was given to that over a long period, with all the signs pointing to inability to meet our needs, only to have the situation completely changed by the unexpected discovery of large high-grade deposits in New Mexico, which now bid fair to make us eventually independent of imports. Emery, on the other hand, which used to be imported chiefly from Asia Minor, has now been largely displaced by manufactured artificial abrasives, instead of by a domestically mined product. Natural sodium nitrate, long an essential import from Chile, has been removed from the list of strategic minerals by bringing to commercial success processes

[25] By T. T. Read.

for the fixation of atmospheric nitrogen and by extending the recovery of ammonia in the coking of coal.

The simplest way to meet our need for strategic minerals would be to find deposits capable of producing them. Perhaps we shall repeat, in some instances, the experience with potash, but it is likely in most cases that we shall be no more successful in the future than in the past in approaching the problem along that line.

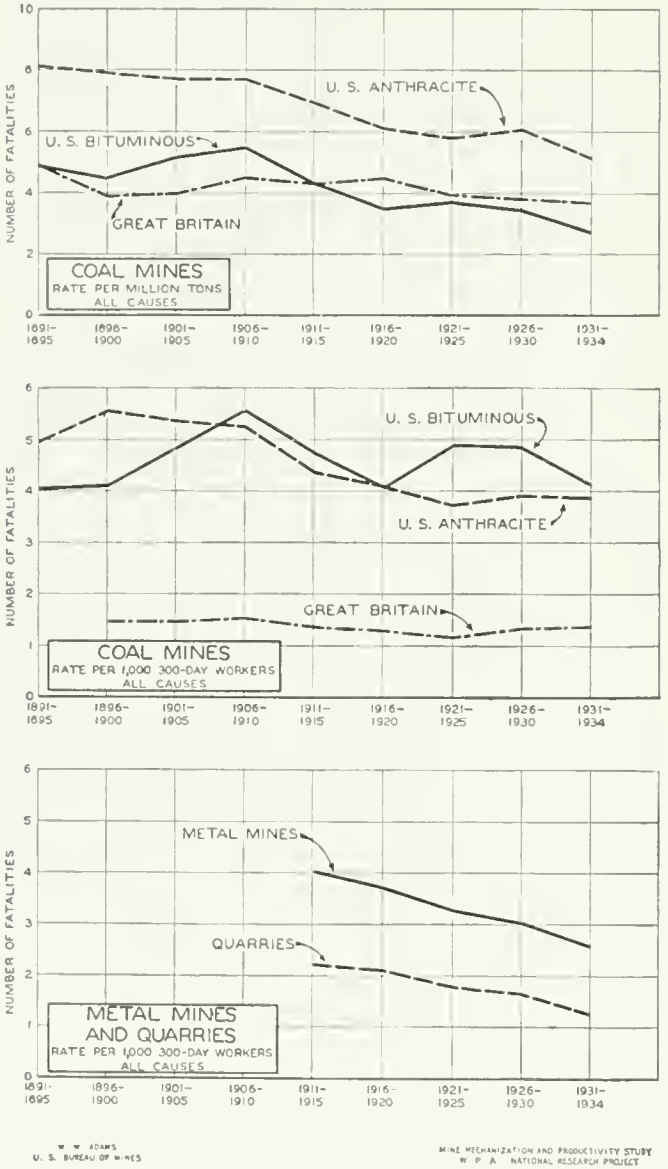

FIGURE 30. Fatal accident rates in American mines and quarries, 1890–1935.

Hazards in the mines have been increased by introduction of machinery and by increasing depth, and in some cases by change in mining practice.

Prevention of the excessively high accident rate in the United States, especially in the coal mines, is as much a problem of education and public administration as of technology.

Encouraging progress has been made in lowering the death rate in quarries and metal mines in coal mines, particularly with reference to explosions.

The technical knowledge now available is sufficient, if fully applied, to effect a great reduction in the accident rate, as the experience of Great Britain and of the best managed American mines has shown.

In some cases there is a fair probability that processes can be developed for converting the kind of material we can produce into the grade that industry demands, in others there seems little possibility of such a result. Changing the technique of the consuming industry so as to use the materials we have has been the most fruitful of results so far. Almost never is the problem one of mining technique, and but seldom of concentration.

No two of the minerals listed are in precisely the same situation, and since limitations of space forbid discussing them individually, it must suffice to say that no major developments, from the mining standpoint at least, seem to be in easy reach.

The social significance of the minerals of the strategic class lies in their importance for national defense or for industrial sufficiency rather than in the volume of employment which mining them might afford. In the case of manganese ore—perhaps the largest item on the list for which there is hope of material production at home—we imported about 700,000 tons in 1929. At 129 tons per man per year, the average for the small number of manganese mines in actual operation, the production of this quantity from domestic ores would have furnished employment to 5,400 men.

New Raw Materials

New mineral substances are that group, some of which have long been known in the museums and others have but recently been discovered, that are either not used at present, or only in small amounts. Developments that would bring them into general use would in effect present manufacturing industry with new raw materials. Some of them are potentially available in large amounts, such as titanium, which is many times more abundant than copper in the earth's crust but until recently was almost unused. This fact might be taken to indicate that there is no mining problem connected with titanium, only one of developing commercial uses. But the principal plant utilizing titanium imports its raw material from Europe because the material produced abroad is more amenable to the manufacturing process used. Minerals containing the metal magnesium are another example. The small production now obtained is derived from the magnesium chloride present in certain Michigan salt brines, but there are also billions of tons of magnesium carbonate in the Pacific Northwest which could be mined cheaply, and seemingly unlimited supplies in sea water. The prospects for cheapening the cost of production of this promising light metal are discussed in Part Three, Ch. VIII.

On the other hand, some of these mineral substances are either rare, in the sense that the total amount known to exist in the earth's crust is extremely small, or else they are so disseminated through large amounts

of other material, like the bromine in sea water, that while the total amounts available are huge, the concentrated material can only be obtained by handling large tonnages. The small amount of radium produced yearly in the world corresponds to the mining of a fairly large amount of the natural mineral which contains it, but even so the social implications of the production of such raw materials lie less in the work of mining itself than in the opportunity for exercise of high technical skill in subsequent operations or in the extremely important human purposes which the final product serves. It is elsewhere (Part Three, Chs. V and VII) estimated that the modern electric light saves a million dollars daily in lighting costs; the tungsten required to produce the lamps made in a year would probably not represent a value, at the mine, of more than $200,000.

Fortunately a number of these substances do not need to be mined separately, our present supply being a byproduct of the final purification of some major metal, as is the case with cadmium, bismuth, selenium, tellurium, and a number of others. The production cost thus becomes largely a matter of bookkeeping, and the selling price usually represents "what the traffic will bear." Bismuth, for example, ordinarily sells for $1 to $1.25 per pound; no one but the producers can tell what relation that price bears to the actual cost of production. How much of it is used in the United States is not known, as the producers do not give out their figures, and most of what is imported comes in as an impurity in lead bullion. One big manufacturer is reported to be willing to use a substantial tonnage of bismuth if the supply is assured at a satisfactory price, but this illustrates a common problem of this group of materials, since the bismuth would displace the antimony now being used in the lead sheaths of electric cables, shifting the demand from one mineral substance to another.

Twenty years ago practically no cadmium was being produced, and the smelters of zinc ore, with which the metal is chiefly associated, at first found it easy to supply the limited demand. The price that resulted from increased uses later drew the copper and lead refineries into recovering cadmium as a byproduct, none of this work representing any increased mining but merely the utilization of something formerly wasted. As soon as the recovery of a byproduct reaches the total amount contained in the ore smelted, the only way to increase the supply is to seek ores richer in the desired byproduct or perhaps ores of the substance itself to be added to the normal ore charge. Commercial mining of such ores hinges on what the smelters will pay for them rather than on a theoretical computation of the value of the ore from its content and the price of the finished metal. Transportation charges to the smelter are another important factor, since such ores are likely to be low grade, and perhaps not easily amenable to concentration. It is highly probable, for example, that the trend will be toward increased intensity of search for cadmium-bearing deposits in the next few years, but as the total consumption of cadmium in this country in 1934 was only about 1,500 tons, not much increased mining will be necessary to double the supply if deposits that are at all rich can be discovered. No such ores are now being produced.

In addition to cadmium, the present demand for selenium, tellurium, and a number of other mineral substances is now met by byproduct recovery. Just what could be done to meet a greatly increased demand no one can surely predict. Arsenic, however, is a byproduct of which the present supply far exceeds the demand. Antimony is only partly a byproduct, and the production is governed by its price level.

The light metal beryllium may be cited to illustrate some of the problems that may arise in developing a supply of a new mineral product. The atomic weight of beryllium is only one-third that of aluminum, and because it is so light the percentage of beryllium to be found in any natural mineral is low; beryl, the ore that will necessarily be chiefly relied on, contains about 4 percent. Beryl ordinarily sells for $40 or less per ton at the mine, corresponding to 50 cents per pound of contained metal. Beryllium alloys ordinarily sell for about $25 per pound of beryllium contained. At first thought it would seem that $40 per ton for the mineral would give a wide margin for mining and concentrating cost, when it is remembered that bituminous coal is mined and sized for less than $2 per ton. But mining beryl is quite a different matter from mining coal; beryl occurs only in what are known as pegmatite deposits, in which it constitutes only a small fraction of the total mass. In contrast to coal, of which the deposits are typically large and regular, pegmatite deposits are typically small and irregular and therefore high cost to mine. The mine price of beryl, therefore, represents a base level and any lowering of the sales price of beryllium must probably come from a reduction of the cost of extracting the metal from the ore.

Outlook for the Scarcer Materials

From what has been said it is clear that the strategic and new minerals are the ones for which technologic trends and their consequent sociological effects are most difficult to predict. The outlook for any one of them is affected by the possibility that geophysical prospecting may uncover mineralized areas which are now wholly unknown, but it may be said that whatever possibilities lie in this direction seem more likely

to belong to a distant future than to the decade immediately ahead. While almost anything may happen, some probabilities can be indicated.

With the background of more than 20 years of study of the manganese problem the only possibility that seems left for much change is the development of a process that will utilize the kind of material we can produce, and the same can be said as regards chromium. Prospects of any substantial production of tin from domestic deposits are poor. Cadmium, selenium, and tellurium have been discussed above. There is hope of finding additional deposits of tungsten, but the use of this metal is threatened by substitute materials, and present mining is a function of tariff protection, as is the case with quicksilver. No change seems indicated in our dependence on foreign sources for cobalt, platinum, osmium, iridium, ruthenium, and palladium.

Cesium, gallium, germanium, indium, niobium, scandium, tantalum, thallium, and an even longer list, can presumably be produced in larger amounts, but even a considerable increase over present levels would still be small, since most of them are little more than chemical curiosities. Locally, of course, they might provide significant employment, since any demand would have to be met by mining, presumably in places where little or none now exists. The broad sociological implications are quite unpredictable, since a small quantity may produce widespread effects. A practicable process for the separation of neon made it available for signs; the quantity needed to produce all the signs manufactured in a year probably would not fill an ordinary sized bathroom. Hence it may be said that, with few exceptions, technologic trends affecting minerals in these two groups will have much greater effects upon the general public than upon that portion of it which engages in mineral production as a way of living.

Technology and Mine Safety [26]

Mining is the most dangerous of the major industries. In 1934 the accident frequency rate in bituminous coal mines was 3 times the average for all industry and the accident severity rate was 6.7 times the general average. Quite apart from the humanitarian interest in reducing the suffering involved are the very practical considerations of the financial cost of accidents and the physical limitations upon underground work which the hazard imposes where it cannot be controlled. Accidents, it is now being realized, constitute an important element of cost, which is largely subject to control. Unless the problem of safety were met the forces of nature underground would prove too much for human strength and skill. From this point of view Sir Humphrey Davy's invention of the safety lamp was scarcely less important than Savery, Newcomen, and Watt's invention of the steam pumping engine in enabling men to mine coal at great depths below the surface.

The problem of reducing the present excessive accident rates in American mines is largely one of education, discipline, and public administration. Constitutional authority to prescribe minimum standards of safety belongs to the State governments and the regulations adopted and educational work done display the wide variation in vigor, intelligence, and competence characteristic of local administration in the United States. The task of the States is undoubtedly rendered more difficult by competitive considerations and by the economic prostration of certain branches of mining, especially of coal. Despite these obstacles, encouraging progress has been made, yet comparison between American and British fatality rates, for example, shows that much remains to be done.

In the field of coal mining the spectacular hazards of gas and coal dust explosions have already been reduced and major disasters largely eliminated (fig. 31). Building on the primary advances of the safety lamp and systematic ventilation, later generations of engineers have introduced short-flame or "permissible" explosives in place of black blasting powder (fig. 31), flame-proof or permissible electrical machinery, electric cap lamps replacing the open torch or carbide lamps, and the practice of rock dusting.[27] These latter advances, now well understood, are winning increasing acceptance and seem destined to general adoption wherever the hazard of explosion is serious. Another possible advance deserving of trial is the Diesel mine locomotive.[28] European mining engineers claim that Diesel locomotives of certain approved types involve less hazard of igniting gas and coal dust than the electric trolley locomotive and that the exhaust gases which condemned gasoline locomotives in the mines are not a serious problem with the Diesel. With these methods and devices at hand, it is now clear that there is no more necessity for a major explosion in a coal mine than for an epidemic of typhoid in a modern city. The problem is largely one of education.

In the related field of mine fires, which have caused some of the worst disasters, in metal mines as well as

[26] By George S. Rice, chief mining engineer, U. S. Bureau of Mines.

[27] "Permissible" explosives and equipment are those officially tested and approved by the Bureau of Mines for use in gassy mines. The value of rock dusting, when efficiently applied, is unquestioned.

[28] Diesel locomotives are not so well adapted for work on heavy and changing grades, a fact which may prevent their use in some cases. Evidently, however, there are many mines in the United States where this would not be a serious obstacle. No locomotives of this type have yet been installed underground in this country. Rice, George S., and Harris, F. E., Diesel Mine Locomotives, U. S. Bureau of Mines, Reports of Investigations, 3320, 1936.

coal, progress is also being made. Here the lines of attack are largely preventive and educational. They have included replacing open-flame lamps with electric cap lamps, lining shafts and portals with concrete, providing fire-fighting apparatus, assuring that the shaft through which men enter and leave shall be used as the intake airway, and training men how to protect themselves if trapped below by walling themselves in and conserving the uncontaminated air. Among the specific inventions in this field are oxygen breathing apparatus and special gas masks.

Mining, like other industries, has its machinery hazards, aggravated by the confined space underground. Electrification raises dangers of its own. As on the surface, the lines of attack include protection from moving parts, careful installation, frequent inspection of equipment, and teaching men to be careful. Some larger mines have installed block signals on haulage lines and automatic controls in hoisting.

But the greatest hazards to life underground are falls of roof or coal. More than half the deaths are due to this cause. When an unfortunate Floyd Collins is trapped alive underground and his untrained friends dig frantically to rescue him, people follow the story from morning to evening in the daily papers. But death through crushing under a sudden fall is so common that it is hardly news. In the year 1929 a total of 1,297 men were crushed to death underground. Prevention of these accidents is chiefly a matter of education, supervision, and discipline. "Ninety percent of the problem is management." But here also the searcher for inventions discovers certain specific ideas or devices that help. Among these are steel props and arches and the development of systems of mining which will avoid the sudden bursts of coal or rock known as "bumps" which develop under certain conditions. Effective lighting at the face makes the signs of danger more visible. The miner himself can be protected from injury and sometimes from death by hard-toed boots, heavy gloves, goggles to ward off flying particles, and steel hats resembling a trench helmet. The last-named device is coming into wide use and has saved numerous lives and prevented many lesser accidents.

No less important than accident under some conditions is the problem of occupational disease. Many underground dusts, such as coal, limestone, and some shale dusts, are thought by many authorities to cause little harm to the human system. But the lead- or arsenic-bearing dusts associated with some types of ore may be poisonous. The most serious problem relates to the siliceous dusts produced by drilling or blasting in rocks high in silica content. Here the lines of attack include delaying the firing of shots until the end of the shift and allowing time for the dust to settle, drilling with water-injection drills, wetting down the broken ore before it is loaded, use of respirators in extreme conditions, and adequate ventilation. The importance of effective ventilation in reducing the hazard of coal-mine explosions or in cooling the temperatures of deep workings has already been mentioned. In addition, it is one of the chief safeguards against silicosis and other pulmonary diseases.

The popular discussion of silicosis now current in the papers doubtless contains much of misinformation, but it will serve a useful purpose in directing scientific inquiry to an important and not fully understood problem. It is not too much to hope that the improvements in mining practice above enumerated, frequent medical examination, and prompt attention to symptoms of danger can keep silicosis under reasonable control and remove this barrier to man's penetration of the underearth.

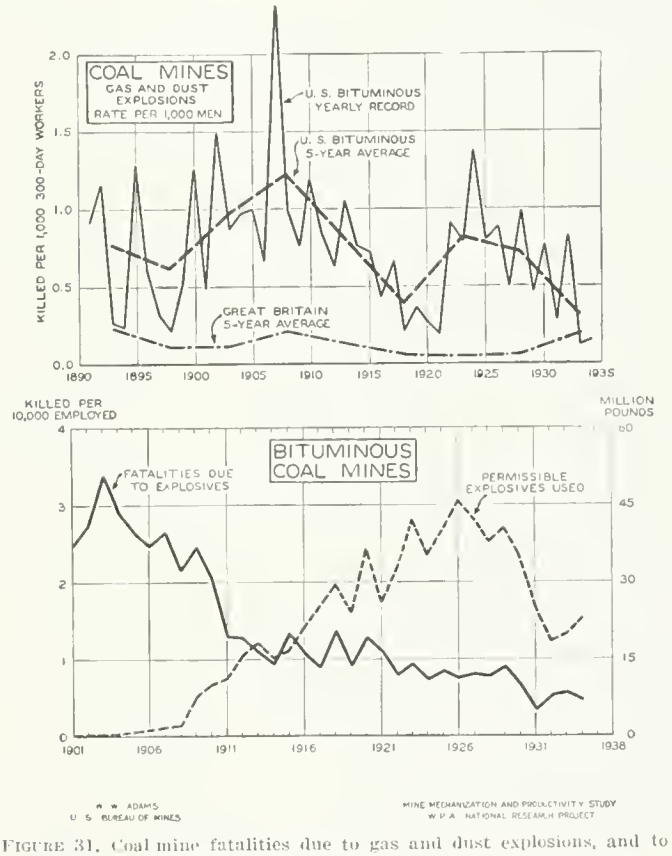

FIGURE 31. Coal mine fatalities due to gas and dust explosions, and to the use of explosives themselves.

Hazards through explosions of gas and coal dust in American bituminous mines reached an all-time high in 1907, declined to 1921, increased to 1924, and have been declining steadily since. Among the developments aiding this result are short-flame or "permissible" explosives, replacing black blasting powder in many mines, "permissible" electrical machinery, closed lights, improved ventilation, and the practice of rock dusting.

The introduction of "permissibles" has also been a factor in reducing the number of fatalities caused by the handling of explosives themselves. Of the total explosives used in bituminous mines in 1935, permissibles constituted 40.4 percent, other high explosives 12.5 percent, and black powder 47.1 percent. (Figures allow for relative power of the different kinds.)

Our discussion will indicate that the problem of health and safety in the mines is as much one of education and public administration as it is of technologic research. On the technical side there is reason to hope that the present death rates from accidents in the mines can be cut in half or more and that the hazard of silicosis or other occupational diseases can be very greatly reduced.

Social Effects of Pending Technologic Change [29]

As in other fields of industry, it is difficult to separate the social effects of mineral technology from related institutional and economic causes. Thus the influence of the mechanical loader in displacing hand labor in the coal mines may be obscured by factors external to mining, such as changes in demand; and again, the impact of unemployment upon the mine worker may be modified by social insurance, shortening of the workday, and by freedom or limitation upon the right of collective bargaining. To attempt evaluation of these other factors would lead far beyond the limits of this book or sometimes into the field reserved for later chapters. Here we are concerned only with those effects that are clearly related to technical change internal to the mineral industries.

In summing up the prospects, it is essential to distinguish between the long- and the short-time view.

The Short-Time Outlook.—The short-time prospect is one of increasing abundance. Generalizing where conditions vary widely, we may conclude that for the immediate future—say for the next 10 years—mineral technology will not only succeed in overcoming the increasing handicaps of nature but may be counted on to effect further savings in the labor required to obtain a unit of product.

For the mineral group as a whole, the increase in output per man hitherto observed may be expected to continue, though probably at a slower pace than during the 1920's. Where exceptions to the general tendency occur and depletion absorbs all of the gains of technology, as may happen in certain of the minor metals, alternative supplies seem assured from other sources or from substitutes.

Whether the savings of labor per ton result in actual decline in employment depends upon the factor of demand, which depends in turn upon many other factors. Without assuming to make a careful analysis, it is clear that the prospects vary with different industries. In coal mining the forces making for labor displacement are strong enough to be a cause of some concern. In metal mining also the chances of expansion beyond the level of the 1920's seem unfavorable. In oil and gas, on the other hand, the trends point to an increase in labor requirements. The relations of the different branches are in part complementary. Thus if metal proves more difficult to win, fuel will be required in greater volume in the mining, concentrating, and smelting of low-grade ores, and if supplies of oil and gas fail to meet expectations, there will be an increase in demand for coal. Under these conditions, a shrinkage in the anticipated demand for labor in the oil-and-gas industry would be offset—probably more than offset—by an increase in the labor needed in coal. Taking the mineral industries as a group, there seems little chance that the total demand for labor will rise greatly above the levels of the 1920's. During that decade technology was able to supply an increase in the national requirements with a diminishing percentage of the national labor force and there is small prospect that the next decade will greatly change this tendency.

Meantime, technology is modifying the kinds of workers needed. The mines will never be a place for weaklings, but the heaviest tasks are the ones most likely to be mechanized. The trend is away from the isolated work of the individual loader and toward work in gangs or crews under increasing supervision. Less independence and more discipline in the miner's task are indicated, less perhaps of sheer strength and more knowledge and skill in operating machinery. Men handling heavy machinery, especially of the mobile type, need quick reaction time, a sense of responsibility, and intelligence. Education will be required for an increasing proportion of the operating jobs—a trend that may attract to the mines youths who would otherwise go into surface industry. The changes do not help the older man.

At the same time, a marked expansion in the proportion of technical and supervisory jobs is indicated.

The changes in technique should aid, but do not of themselves guarantee, improvement in working conditions. Reduction of the present excessively high accident rates is brought within reach. Increasing efficiency helps the employer to pay higher wages. It also aids reduction in working hours, and the last generation has seen the working day underground reduced from 9 or 10 hours to 8 in metal mining and 7 in coal. But the degree to which these technical gains are translated into advance of labor standards depends largely upon other factors—upon the economic stability of the mineral industries, on the adequacy of State mining codes, and on the bargaining power of the men.

The changes of technology point toward concentration of mineral production in a smaller number of larger and more efficient plants. Discovery of new deposits acts, of course, to increase the number of producing centers, and in oil and gas a multiplication of producing units is still in progress despite a marked

[29] By F. G. Tryon.

increase in average size. In many other branches of mining the number of plants was declining even before the depression. The growing investment resulting from mechanization requires larger operating units. Indeed, the increasing size of the fabricating establishments that consume the raw mineral works toward larger mines in order to provide the reserves necessary to protect the investment in manufacturing. The exceptions to this tendency, such as the revival of placer-gold digging during the depression, the bootlegging of anthracite, the little truck mines springing up in the bituminous-coal fields, or the portable sand and crushed-stone plants, are more spectacular than important. Over the mineral industry as a whole technology is forcing concentration into larger units.

The increase in size of unit, in turn, affects the location and the size of mining towns. Fewer company towns will be built in the future. A slow drift from isolated camps to central communities is already under way. More and more of the mine workers will live in permanent towns and ride to work in the surrounding area. The change is due chiefly to the external factors of hard roads and cheap automobiles, but it is facilitated by the centralized operation which the trend of mineral technology is favoring.

Technology is also working to increase competition between one branch of mining and another. More and more, one metal substitutes for another, while competition between the several sources of fuel becomes more fluid and more interchangeable. The change is, of course, largely due to developments in the consuming industries which are sketched in the chapters on metallurgy and the power inventions, but it is also stimulated by the advances in refining, preparation, and pipe-line transport outlined in this chapter. This interindustry competition—so striking as to elicit the name of "the new competition"—has become a major factor in the economic environment of coal, oil, and gas, and the major metals. It aggravates the problem of economic stability. To balance supply and demand becomes more difficult for any one of the fuel industries acting alone or for any State government acting alone. The drift plainly observable toward collective action to control the more destructive forms of competition is stimulated by the changes of technology.

The effects thus far sketched concern chiefly those engaged in mineral production. What are the effects upon the consumer of the product? How far is mineral technology achieving its mission of providing industry with an abundance of cheap fuel and cheap raw material?

Here again the short-time answer seems fairly clear. The decrease forecast in man-hours per ton of mineral, other factors remaining constant, should permit a reduction in cost to the consumer. The actual prices paid by the consumer depend also upon the allowance for profit to capital and wages to labor in the mines. As both of these fell below reasonable standards dur-

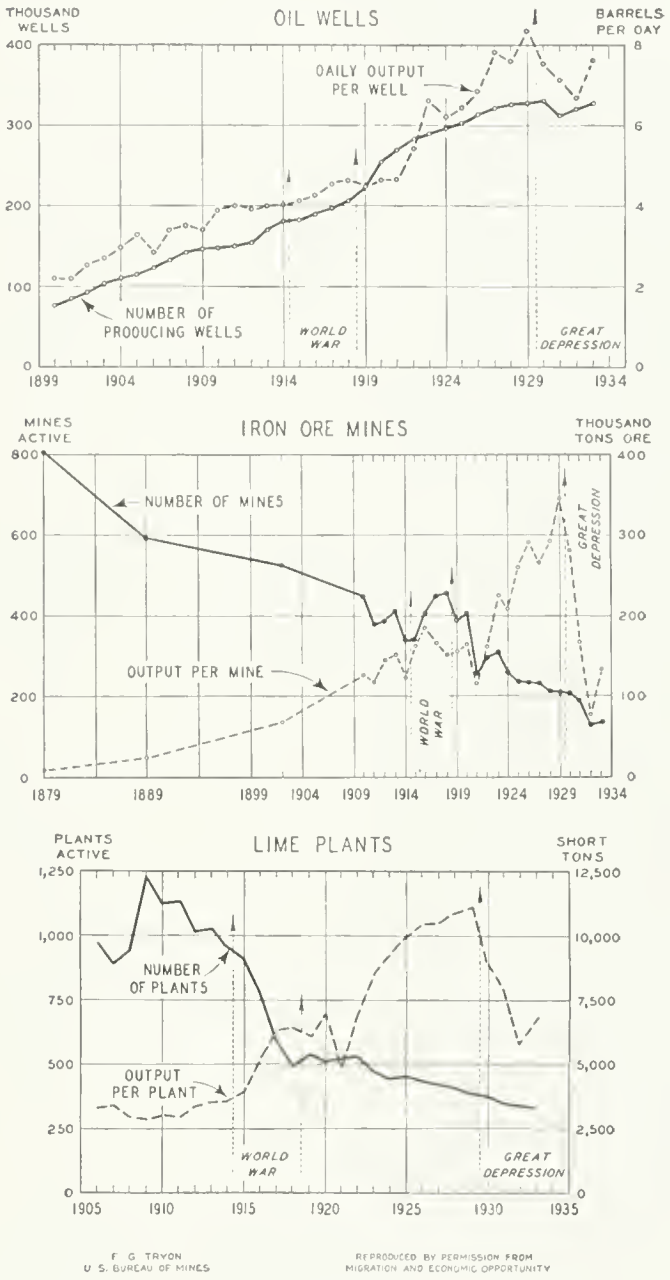

FIGURE 32. The trend toward concentration of mineral production in larger units.

Technical changes in the mineral industries, reenforced by market factors and exhaustion of the more accessible outcrops, are tending to concentrate production in a smaller number of large mines or plants. Thus in the oil industry the daily output per well has increased fourfold since the turn of the century, although in this case discovery of new fields has also resulted in an increase in the number of producing units.

In the iron ore and lime industries, on the other hand, the increase in size of plant has been accompanied by a sharp decrease in number of plants.

Partly as a result of this tendency and partly because of improved roads and cheap motor cars, the mining population is beginning to drift away from scattered camps and to concentrate in central towns from which the men travel out to work.

ing the great depression, some increase over recent levels of price seems both probable and fair. Prices of individual minerals, especially of the high-value metals, are much affected by world markets, and all prices are affected by monetary policy. We can speak, therefore, only in terms of the relative prices for minerals in relation to the all-commodity level. Generalizing where numerous exceptions will doubtless appear, especially for short periods, we may say that prices to the consumer during the next decade should hardly exceed those of the 1920's, wage rates being equal, and in many lines are more likely to be lower.

With respect to the strategic minerals, generalization is especially difficult. The prospect for any one of those on which the Nation is now chiefly dependent for imports is much affected by the uncertain factor of exploration and discovery. For the group as a whole we may be fairly sure that technology will provide an increasing variety of materials or an increasing effectiveness of substitution. More of the shortage group may be expected to pass into the group of assured supply either by discovery of domestic deposits or by synthetic processes of manufacture, or by metallurgical processes suited to low-grade domestic ores. But while technology seems likely to make us less rather than more dependent on imports for national defense, the practical task of preparedness should reckon a bird in the visible stock pile as worth two in the synthetic bush, and the simplest and cheapest provision against wartime shortage, until the alternative source is proven, is a purchased reserve maintained under safekeeping.

Much the same outlook seems to hold for the rare materials for which price rather than dependence upon foreign sources is the factor at present limiting supply. Regarding this group we may count upon occasional discovery and cumulative technical advance working to increase supply and reduce costs. As yet, however, technology has given no assurance of revolutionary change in this quarter.

The prospect for the coming 10 years may be summed up as follows: Aside from the hazard of war, technology and its allies—exploration and transport should be able to supply all the fuel and earth material that the world can consume at prices not greatly different from those to which we became accustomed during the 1920's. At the same time we may prepare for numerous shifts in demand, fluctuations in the prices of individual minerals, local exhaustion with forced readjustment of stranded populations, migration to newer centers of production, and in some branches increased dependence upon imports except as the pressure of marginal producers forces concessions in protective tariffs. Such is the short-time outlook.

The Long-time Outlook.—Over the longer view, however, the prospect is one of growing difficulties in which technology has a harder time to overcome the handicaps of nature. The arrival of such a stage of increasing cost is forecast by the past experience of individual mines and the older mining districts the world over. When the time comes that new sources are no longer available, more of the world's mineral industry must pass into the stage already locally familiar where the gains of technology can no longer suffice to offset the increasing handicaps of nature.

Unfortunately for social planning, we can be much surer of the probability of such a period of increasing costs than of the date at which it will appear. It depends most of all upon the highly uncertain factor of the reserves of oil and gas recoverable from natural reservoirs by drilling wells. Oil and gas are the cream of the energy resources, and the cream is thin. When it becomes necessary to supply motor fuel from alternative sources, such as coal and shale, or to recover metal from ores much below present commercial grade, the machine civilization must be prepared to pay higher prices for the products of the underearth and to devote an increasing proportion of its labor force to the task of mineral extraction. It is doubtless conceivable that such a period of diminishing abundance of minerals should emerge within the next 10 years, but more likely that it will be longer delayed.

It is the prospect of such an increase in costs that creates the problem of mineral conservation. Absolute exhaustion of any mineral could happen, if at all, only in the distant future; increasing cost through depletion of the best resources has already arrived in some branches of mining and may be expected in still others within the span of men now living. It is, therefore, the simplest common sense to prolong the period of abundance by the elimination of preventable waste. Despite commendable progress, waste of coal, natural gas, petroleum, and, to a lesser extent, of certain of the metals, continues on a scale so great as to deserve "the measured use of the word intolerable."[30] Avoidance of these wastes is a major social problem, but it depends less upon technical than upon economic and institutional factors, such as industrial stability or modification of the law of capture in the production of oil and gas. These problems have been outlined in other studies of the National Resources Committee and require no further mention in a report upon technology.[31] On the whole, the technologic developments in prospect increase the potential recovery of the resource. The problem of conservation is largely to encourage an organization of the mineral industries that will permit the savings in resources which technology has already shown to be possible.

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[30] Report of the Planning Committee for Mineral Policy, National Resources Board Report, Dec. 1, 1934, p. 392.

[31] *Idem*, pp. 391–434.

III. TRANSPORTATION

By Harold A. Osgood[1]

The Importance of Transportation

Whether or not we agree with Kipling's assertion that "transportation is civilization", it is plain that most of our present civilization is dependent on transportation for its existence and that the transportation industry itself is one of the most important factors in the economic and social life of the United States.

The Federal Coordinator of Transportation recently found over $27,000,000,000 invested in rail, pipe-line, and waterway transportation in this country. To this investment at least $2,000,000,000 may be added for motortrucks, many billions more for privately owned automobiles, and correspondingly great sums for improvements of inland waterways, rivers and harbors, and our 3,000,000 miles of highways. Air transportation is an industry in which millions in new capital are being added annually.

Similarly impressive statistics as to employment, purchasing power, taxes paid, etc., are readily available and, in a general way, familiar to all who have given even the most casual attention to the subject.

Probably any extended discussion of the part transportation has played in our history would verge on "a blinding glimpse of the obvious." Economically the United States is the world's greatest experiment in free trade within its borders, spread within our continental limits over about 3,000,000 square miles of land of the widest diversity. That our 48 States could ever have been developed or united, or that the present Nation could be held together without a great and efficient transportation system, is highly improbable.

Our Present Transportation Service

In attempting to ascertain the present scope of freight and passenger traffic in this country, the investigator ventures into a strange and terrible jungle of statistics. Not only are the figures of a size usually associated with astronomical calculations, but a regrettably large amount of the basic data would have delighted Mark Twain's Connecticut Yankee, who discovered that in King Arthur's day one merely had to state one's facts and was not required to prove them.

Railroad statistics are compiled accurately and in expensively elaborate form; waterway figures are accurate and detailed; but do not include ton-mile data for coastwise or intercoastal traffic, and do include a large amount of short-haul intraport traffic at places like New York and San Francisco (the equivalent of a railroad switching service); pipe-line figures have to be adjusted arbitrarily for intrastate traffic; while motor-transportation statistics are scarcely to be dignified by such a label. Ton-mile figures for motor-truck traffic, for example, have ordinarily been derived from an assumption that 50 percent of truck-miles are purely local, an estimate that empty mileage of trucks amounts to 33 percent, a conjecture that trucks on the average load to 80 percent of their capacity, and a guess that the average truck makes a certain arbitrary mileage per year. Wherein such a mathematical guess is superior to the ordinary or inspirational guess is problematical.

Within fairly broad limits, and following mainly the study of the Federal Coordinator's Freight Traffic Report, freight service in the United States appears to be divided as follows:

Freight traffic in the United States, 1932

	Billion ton-miles	Percent
Railway	236	69
Pipe line	32	9
Water	37	11
Highway	35	11
Total	340	100

The passenger traffic situation, based entirely on the Federal Coordinator's reports, is as follows:

Passenger traffic in the United States, 1933

	Billion passenger-miles	Percent
Common carriers:		
Railway	16.3	4.3
Bus	3.4	.9
Airway	.2	.1
Total	19.9	5.3
Private automobiles:		
Intercity	184.9	48.9
City	173.0	45.8
Total	357.9	94.7
Grand total	377.8	100.0

Probably it would be even better to say that the railroads perform about two-thirds of the freight service.

[1] By Harold A. Osgood, Vice President, Fulton Iron Works Co., St. Louis, Mo., assisted by a committee under leadership of Frederic A. Delano, National Resources Committee.

and that the balance is divided fairly evenly between highways, pipe lines, and waterways.

As a result of the inaccuracies and lack of similarity in data, such wide differences of opinion as usually arise from uncertainty as to facts have grown up and even been reflected in graphic charts and expert reports prepared for the enlightenment of students of the transportation problem and for the public in general.

Grand Total

Here again it is plain that with 24,200,000 private automobiles registered in the United States, and completely free from any statistical obligations whatever, the necessary facts as to total automobile mileage per year, the number of passengers carried in addition to the drivers, and the division of travel between intercity traffic on the one hand and going to the corner grocery or the neighborhood movie on the other are totally lacking. Probably here it should be enough to say that the overwhelming bulk of our passenger transportation is performed by private automobiles. The division of the remaining 5 or 10 percent which is handled by common carriers seems accurate.

Twenty years ago the Supreme Court condemned some exhibits before it as an example of "setting down figures with delusive exactness." No better characterization could be found for many transportation statistics.

The General Future of Transportation

In considering the future of transportation over the next 20 or 25 years it will be advantageous to deal first with freight and passenger traffic as such and without regard to the individual agencies performing these services.

Freight

It appears unlikely that freight traffic measured by ton-miles will increase materially beyond the standards which prevailed prior to 1930. In the first place, we use a great deal more freight service per inhabitant than other countries do; 1933 figures (except for France and Switzerland, where the averages cover the year 1934) are given by the Bureau of Railway Economics as follows:

Country:	*Ton-miles (railway) per inhabitant*
Great Britain	430.25
Germany	526.21
France	590.36
Sweden	368.72
Italy	141.18
Switzerland	282.69
India	77.44
Japan	133.12
Canada	2,247.37
United States	2,137.96

Granting that the proportion of motor truck and waterway service in these countries may differ somewhat from our own, and making whatever allowance seems reasonable for differences in area and density of population, the United States still seems to use a disproportionate amount of freight service as compared with older and more settled and stabilized countries.

The trend of our population is toward stabilization. The Census Bureau thinks that 11 of our 48 States have fewer inhabitants than in 1930. We have various persuasive historical studies of our vanished frontier and its profound effect; we have reached the stage where governmental efforts are being made to retire land from cultivation and settlement. The United States still has room for many million additional inhabitants, but beyond the horizons which are new to them are dude ranches and hard roads.

The second factor limiting the growth of freight transportation is not advanced science and revolutionary inventions, but prosaic common sense stimulated by competition. Everywhere the industrial world is trying to eliminate useless transportation, and the cumulative effect is already noticeable. A good instance in the not distant past has been the production of steel, using hot metal direct from the blast furnace and eliminating the transportation of pig iron and of the fuel formerly used to melt it. Other examples are the shift of the textile industry from New England to the Southern States, and of the shoe industry from the East to the Middle West. Location of industries where freight costs can be saved is a conspicuous factor. Manufacturing plants are being built out of savings in freight rates. In lighter manufacturing particularly an undoubted tendency toward relocation and dispersion of industry is evident, although this tendency does not arise from transportation considerations alone.

Probably even more important than such factors over a long term of years is the elimination of waste, not merely waste freight transportation arising out of bad location of industry and from circuitous hauls but waste of materials. Conspicuous examples are the waste of coal in domestic heating and small power plants, evidenced by our smoke nuisance, waste of gasoline through bad carburetor adjustments, etc., and waste of oil burnt under boilers at a fraction of the efficiency at which it might be used in internal-combustion engines. It is not necessary to review the literature on this subject—for over a generation we have all been schooled to believe that the United States is the most wasteful Nation in the history of the world, and the technical aspects of the situation were given wide publicity by former President Hoover. Nor need we argue whether so great a Nation as ours could

have been developed so rapidly without a large if not a disproportionate amount of waste.

Any study of freight transportation of the future, however, must recognize that if, say 20 or 25 percent of our materials are being wasted, we have a corresponding amount of freight transportation awaiting elimination.

This naturally leads to the third factor limiting freight transportation—advanced technology, including, of course, the use of materials at present wasted, but particularly affecting traffic through the production of better materials and the manufacture of better designs. Developments along these lines in the fields of agriculture, mining, the chemical, and metallurgical industries in the production, transmission, distribution, and uses of power, etc., are treated in the various other special and general papers comprising this entire study of technological trends and their social implications.

Freight traffic is peculiarly a product of factors beyond its control, and in a survey of such factors must be read the future of the transportation of freight—both as to its volume and its character. We have better and longer-lived materials. We ride on tires advertised to run 20,000 miles, and coming much nearer to meeting this standard than the guaranteed 3,000-mile tires of 20 years ago came to the claims of their manufacturers. The American Iron and Steel Institute calculates that the 34,000,000 tons of steel produced in 1935 may be expected to last an average of 32 years, or approximately twice as long as steel did 40 or 50 years ago. The development of alloy steels, minimizing rusting and making the steel itself stronger and more durable, improved manufacturing eliminating impurities, improved processes for coating steel products with tin and zinc to resist corrosion, and the refinements in manufacturing processes and rigid tests assuring higher quality and insuring fewer replacements once the steel is in use, are pointed out by the Iron Age as factors in lengthening the life of steel.

As in material, so in designs—particularly designs permitting the use of higher speed, lighter machinery. This general field is far too broad to serve as part of a special report on transportation—plainly, however, any increases in freight traffic do not lie in this direction.

A fourth factor, not merely limiting freight transportation but making constant, direct inroads into the volume of freight service required, is the competition of electric transmission lines and natural-gas pipe lines.

Coal has long been the backbone of railroad tonnage; it is a large element in water transportation, and in many areas it is handled in great quantities by motortrucks. In 1928, a fairly typical year, for instance, about a third of all the tonnage moved by the railroads was coal, which also produced about a fifth of all the freight revenues. Cutting into this transportation of fuel is the electric-power industry, employing a fourth as many persons as the railroads operating over 200,000 miles of transmission lines, transmitting around 100,000,000,000 kilowatt-hours of electric energy annually and striving to minimize the haulage of its own fuel. Fuel for this industry does, of course, move in tremendous tonnages, and these tonnages may increase with increased use of steam-generated electricity.

It is true also that generating plants cannot ordinarily be located at the mines on account of the lack of an adequate supply of cooling water. Beyond certain distances electric energy cannot be transmitted cheaper than coal can be hauled; electricity cannot be stored in wholesale quantities, and coal can.

Subject to these limitations, however, electric-power companies naturally try through the location of their plants to reduce haulage of coal. Plainly, improvements in electric transmission may decrease transportation of coal. The amount of coal required per unit of electric output is being steadily reduced.

Moreover, as about one-third of the electric energy generated by public utilities is now developed by water projects as Boulder, Grand Coulee, and Norris, the transportation of coal will be further affected. Some of these projects serve portions of the country where cheap coal is not available and will involve little direct displacement of coal, the fuel replaced, if any, being oil or gas. Others, however, will tend to limit the transportation of coal. It seems improbable that the national requirements for bituminous coal will exceed the 1929 level for some years to come.

Less known to the general public is the growth of natural-gas trunk pipe lines. In 1931 there were about 70,000 miles of these and probably $3,000,000,000 is invested in this industry, which is said to have more than 5,000,000 domestic customers. Forty-four percent of the production of natural gas is used in drilling oil or gas wells, or for the manufacture of carbon black. The balance represents direct substitution of gas for other fuels, chiefly coal and oil—equivalent to over 40,000,000 tons of coal a year, and the industry is progressing at a rate undreamed of by the average person.

While freight traffic, measured by ton-miles, will probably increase but slowly above the normal levels of the past, lighter and bulkier freight will in some measure serve as an offset from a revenue and even from a carload or truckload standpoint. Such items as electric refrigerators and radios have reached a surprising volume in recent years. A large traffic in fruits and vegetables, from such distant territories as the Rio Grande and Imperial Valleys, has grown up, and the near future will probably see increasing

movements of air-conditioning and insulating equipment and materials, portable houses, trailer bodies, and the like. These increases in volume will partly compensate for reductions in weight.

While no great, new, heavy industry has appeared on the horizon, many new lighter industrial and manufacturing activities are in plain view. This trend will call primarly for flexibility and speed in transportation.

On the whole, however, the gradual increase of population appears as the principal favoring factor in the freight situation. Against this may be set off some of the most vital influences in our economic life.

Passenger

The probable future of passenger transportation presents a striking contrast to the freight situation. The urge to travel is undoubtedly a deep-seated human characteristic. Not only has it been evident from the earliest times down to date but a yearning for "fresh fields and pastures new" is apparent through the widest ranges of social classes. No more striking example of this general thesis can be found than in the United States. Here the average travel per inhabitant was about 500 miles per annum in 1920, and over 2,000 miles per annum in 1929.

In the words of the Federal Coordinator (from whose Passenger Traffic Report these figures are taken), "within less than a decade, American travel desires and habit were quadrupled, and at the end of 4 years of depression, were still more than three times as great as they were prior to the automotive era."

In a paper read before an international congress for traffic problems at Vienna on June 16, 1936, the director of the Austrian Governmental agency for the development of tourist traffic predicted that the next few decades will bring a gigantic rise in intercity and international travel, and that this mass travel—at low fares—of the near future will have to be carried primarily by the railroads as the only agency capable of handling it. These statements, based upon intense study, come from a neutral source, interested only in traffic problems as such.

All increases in leisure or in speed of travel and all decreases in transportation costs promote passenger travel, and the more people travel the stronger is their desire to do so.

Better forms of communication will take the place of some passenger traffic. The long-distance telephone has saved many business trips. If to this television is some day added, and if the costs of all such services are cheapened, communication may further supersede transportation. Such changes, however, are probably in degree rather than in character. The savage with his drums and smoke signals, the Romans with their system of flaring beacons, the mails, the telegraph, the telephone, and the radio, all have served as substitutes for travel.

Doubtless, too, a large portion of our travel is recreational or partly so, and this is not influenced by communications.

In the face of the quadrupling of our own passenger traffic in recent years, it seems improbable that communications will seriously limit travel. Ability to make more speedy and numerous contacts through improved communications may even be an item making for increased passenger transportation.

Unlike freight, where all the railroad or other common-carrier advertising, education, and solicitation in the world will not make tonnage move beyond the economic needs of the time, the passenger-transportation market is even today capable of large expansion.

Highway Transportation

Probably the road passing the front door touches the lives of the people closer than any other transportation facility. Certainly the average man has both a more intensive and a wider knowledge of our highways and the vehicles using them than of any other phase of transportation. On December 31, 1935, the miles of road in the United States were as follows:

Existing types	Grand total	Total State	State primary system	Secondary roads under State control	Local roads
Nonsurfaced	2,052,263	[1] 148,419	52,060	96,359	1,903,844
Surfaced	981,737	357,051	279,807	77,244	624,686
Low type	818,835	242,708	168,282	74,426	576,127
High type	162,902	114,343	111,525	2,818	48,559
Total	3,034,000	505,470	331,867	173,603	2,528,530

[1] Includes 63,628 miles fully graded and drained, and ready for surfacing.

The data given above as applied to State primary road systems and to secondary roads under State control are accurate enough, but the local road figures are not supported by equally reliable statistical information.

Primary Road System

We have a well improved system of through routes traversing States, regions, and the country as a whole, connecting our principal cities and generally adequate for the traffic. It should be noted, however, that almost none of our transportation maps, whatever the agency, show density of traffic. The Lincoln Highway averaging fewer than 100 vehicles a day in Western Utah, looks just as big on the map as the six or eight-lane superhighways in the vicinity of our greatest cities.

The Bureau of Public Roads of the United States Department of Agriculture reports that main and through highways are now being designed to allow

safe travel at speeds of 60 miles an hour or more. With such speeds in mind, our main roads will have smooth and skid-resistant surfaces, careful alinement, effectually moderated grades and curves, and the opposing lanes of travel should preferably be separated.

Horizontal and vertical curvature will have to be reduced to permit clear vision of not less than 800 feet on curves and at the apex of grades. Where shorter sight distances cannot be avoided, markers should be set up showing the safe speeds at which the curves can be negotiated. In the case of three-lane highways on which the middle lane is used intermittently for passing, sight distances up to 1,200 feet are desirable.

Intersections with heavy traffic roads will require grade separation structures, less important crossings may be protected by islands in the main road so that vehicles can find protection between these islands, and accomplish the crossing if necessary in two movements through breaks in the opposing traffic stream on the main road.

Access to high speed roads will, of course, have to be regulated. Abutting property owners cannot be allowed to enter the right-of-way wherever they choose, nor be permitted to utilize their frontage indiscriminately for parking purposes or the sale of hamburgers and red china dogs. Special stopping places with suitably widened and protected shoulders should be placed along the road for the accommodation of busses and rural mail delivery cars. Safety and road utility, maintaining an unobstructed full width of pavement for through traffic, are the paramount considerations.

As traffic gravitates toward the most highly improved roads, the superior design and control of the future high speed main highway systems will lighten demands on secondary roads. Much of the cost of expensive high type construction of the main highway may thus be saved in the less costly nature of the secondary road systems.

Quoting the Bureau of Public Roads directly:

> If the volume of traffic on the main road does not exceed 4,500 vehicles daily, a two-lane pavement should suffice, but on account of the speed it should be 22 feet wide, thus giving ample room for passing, even allowing for the reluctance of operators to drive near the edges of the pavement. Still remembering the high speeds the through road will be designed to accommodate, it will probably be found safest to increase the capacity of a two-lane road by building another two-lane pavement on the same or a widened right-of-way, the two pavements to be separated by a neutral strip, and each used for one-directional traffic. When the traffic density exceeds the capacity of a four-lane pavement, it will be advisable to locate wisely a parallel through road on a new right-of-way, so as to spread the benefit to a wider area of secondary road territory.
>
> The high speed roads will require sidewalks for pedestrians, especially in populated regions, and the walks should be attractively smooth, in order to keep pedestrians off the road surface. Here again besides accident prevention the consideration will be, as in the cases of widened bus and mail carrier stopping places, to keep the through road clear for fast traffic.
>
> Highway lighting presents further possibilities of refinement in the safe operation of high speed through roads. The cost of installation is not excessive at $2,500 to $3,000 per mile, but the annual operating expense estimated at $600 to $1,000 per mile exceeds all usual charges against maintenance. State highway departments may, therefore, hesitate to assume this added expense. Nevertheless, because of the large savings resulting from accident prevention, coupled with the gain that would surely come from speedier movement of traffic, it may reasonably be expected that the through roads will be well lighted in the not distant future.
>
> The already designated State primary system of highways including the Federal-aid highways will be the logical starting points in the development of high-speed, through routes, and the areas of great population density in the country will benefit most from the early beginning of such a program, for example the regions from Boston through to Washington, from Philadelphia or Baltimore to Pittsburgh, from Pittsburgh to Cleveland, from Cleveland to Detroit and Chicago, and from Pittsburgh through Columbus and Indianapolis to St. Louis.
>
> The interurban through roads will be provided with branch connections entering the metropolitan areas, as well as high-speed bypasses around the large cities, instead of continuing the present practice in many places of dumping the highway traffic into the city streets, causing much congestion, and needlessly delaying the vehicles which are driving through and beyond the metropolis.

Secondary Road System

We now come to the secondary or branch system of roads which will feed the high-speed, through system. The improvement of the secondary highways is the part of the program that brings the road facilities, speaking broadly, to everybody's front door. It is the part of the program which has been considerably neglected in the past, because of the very apparent primary need of improving the through routes. But the wider the improvement of the secondary system the better will become the whole highway facility, and the larger will grow its usefulness and value.

The great advances accomplished in the science of road building during recent years have helped indicate a satisfactory solution of the problem of the secondary road. In other words, the understanding gained of the reactions of subgrades to moisture, temperature changes, and wheel loads transmitted from the road surface; the development of better drainage methods; the study of scientific blending and sizing of road-surfacing materials; the use of chemicals and bituminous products; and finally the perfection of most efficient road-building and road-working machinery have all gone a long way toward rendering the low cost, lower traffic road a safe and sane investment.

Although conditions and costs of construction will vary widely in different parts of the country, it would be fair enough to put the cost of bituminous macadam at two-thirds that of a concrete road, and, if well built, the macadam would carry a traffic of 2,000 to 2,300 vehicles per day without injury. From there on down through the types of treated and untreated macadam, treated and untreated gravel, and plant or road bituminous mixtures, it is possible remarkably to cheapen road improvement and to secure satisfactory performance under the

lower traffic densities. As the work of improvement progresses among the secondary or feeder roads there will be a tendency toward more adequate alinement for higher speeds, the reduction of grades, and the substitution of smoother surfaces, because the lowering of motor-vehicle operating costs will also demand consideration.

Highway plans are therefore based on a primary system of high speed, through roads adequately and safely designed in respect to location, alinement, surface, and rights-of-way with controlled frontages. These through primary roads will automatically attract traffic off the secondary feeder systems, which will be of generally less expensive construction, but, nevertheless, capable of carrying the moderate volumes of more slowly moving vehicles.

The Vehicles

In 1935 there was one registered motor-vehicle for every 4.79 persons in the United States as compared with one for every 5.30 per motor vehicle in 1933. At the end of 1936, 24,200,000 passenger cars and 3,800,000 trucks were registered, both figures establishing new records and the much-discussed saturation point still not imminent.

A complete analysis of 1932 ownership was made by the Bureau of Public Roads, showing the highest degree of automobile ownership in California, where there was one car to every 2.77 people, and a generally decreasing ratio of ownership from West to East—for instance:

Colorado	3.60
Kansas	3.70
Ohio	4.05
Pennsylvania	5.72

In Arkansas one car was registered to every 13.27 people and in Mississippi one to every 12.85, as compared with one car to every 3.46 people in the State of Washington and 3.64 in Oregon. The average for the United States in that year was one car for every 5.16 people.

In the face of such figures it would be hazardous to reach any specific conclusions as to where automobile registrations will stabilize in reference to population, although the tendency of the registration curve will probably finally be to flatten out and approach a curve parallel to the curve of population.

While leaders in the motor industry are by no means fixed in their views and decidedly not unanimous, the general trend appears as follows:

Passenger Cars

Size.—About the same as at present which, after all, is based on the size of human beings. The small English and Continental cars are the products of taxes on large motors, the high prices of fuel and lubricants, the distances, and the character of roads.

Weight.—Undoubtedly less, through the continued development of lighter metallic alloys, the possible cheapening of aluminum, etc.

Speeds.—Not much beyond the performance of current 1937 models. From a standpoint of safety, a good deal of resistance to increased highway speeds has grown up, even where fast travel may be feasible. If, however, we have roads and cars permitting comfortable, economical, and safe operation at speeds of 60 miles an hour or more, we shall probably make use of such transportation facilities. Indeed, public desire to drive at high rates of speeds over modern highways, and the unwillingness of good drivers to be at the mercy of utterly unfit operators of automobiles are bound to force greater supervision of the drivers themselves. The right of "the maim, the halt, and the blind", not to mention the financially irresponsible, the drunken, the reckless, and the miscellaneously unfit to operate motor vehicles, is not guaranteed by the Constitution or the Declaration of Independence.

A surprisingly wide public sentiment, however, seems to regard the ownership and operation of a motorcar as God-given rights quite as inalienable as "life, liberty, and the pursuit of happiness."

Streamlining.—Some trend in this direction beyond today's designs, but probably the gradual working out of details rather than radical changes made at the sacrifice of comfort.

The influence of streamlining on automobile design is definitely apparent in all our cars today, but under ordinary conditions its value has been less than recent developments in reduction of weight, particularly unsprung weight, widening seats, use of steel bodies, changes in springs, shock absorbers and stabilizers, improvements in steering, and so on.

Mechanical and Electrical Features.—Constant minor improvements.

Supercharging.—Supercharging as a means of compensation for rarefied atmosphere at high altitudes is not needed in the ordinary automobile, however indispensable it may be to a combat plane. At ordinary speeds and under every-day normal operating conditions, it is difficult to get additional power more cheaply through supercharging than by the more prosaic method of using a somewhat larger engine or a higher compression ratio. Nor has the increased cost of supercharging been offset by operating savings. The requirements of specially constructed racing cars and 6-mile-a-minute planes are not those of the ordinary family automobile.

Superchargers, however, give cars much greater acceleration at relatively high speeds (45–50 m. p. h.) and are thus useful in passing other vehicles, especially on narrow roads and with heavy opposing traffic. How much importance car buyers attach to this ability re-

mains to be seen. If the demand is for rapid acceleration, or as the salesman calls it "performance", rather than for economy, we shall probably see more cars with superchargers.

Fuel.—Most obviously depends on the continued supply of oil. Gasoline and Diesel engines can be built with about the same weight per horsepower, and the costs of the engines themselves are not materially different. The fuel injection system on a Diesel, however, requires far more accurate and expensive machining and construction than the gasoline engine's carburetor and is completely out of the class of things that can be fixed by the average owner or garage.

It should be borne in mind that most of the comparisons of Diesel fuel oil costs with gasoline are misleading. Fuel oil is not generally taxed. Gasoline frequently carries a sales tax ranging from 30 percent up to in excess of 100 percent. Of course, a shift from gasoline to fuel oil consumption would almost immediately be followed by corresponding taxes on fuel oil.

Furthermore, fuel oil at present bears almost none of the distribution costs of gasoline such as filling stations, newspaper and magazine advertising, and radio comedians.

Naturally, also, an increased demand for fuel oil, which is made out of the same crude petroleum whence gasoline is derived, would increase the price of fuel oil.

Basically more important than any of the foregoing considerations is the fact that the cost of fuel, whether the average owner is enough of a cost accountant to realize it or not, is a rather small part of the cost of owning and operating an automobile. It seems doubtful if enough operating expense can be saved using a Diesel engine in a motorcar to pay for the increased cost of a Diesel fuel injection system—which might easily amount to over $200 or $300 per car.

On trucks and busses the Diesel has possibilities owing to the larger use of fuel in relation to the relatively fixed cost of a Diesel fuel injection system.

The use of alcohol, or more probably gasoline-alcohol mixtures, would not present any serious technical problem to the motor industry. While the economic problem of increased prices for fuel might become important, and while alcohol undoubtedly has less heat energy and causes far more corrosion than gasoline, engines can be built to run on it.

The real uncertainty as to fuels—an intangible possibility which may genuinely revolutionize the internal-combustion engine—lies in the research laboratories, particularly those of the chemical and the oil companies. If coal or crude petroleum is some day reduced entirely to gases, and these gases in turn are polymerized and converted to liquid fuel with resultant changes in the molecular structure, builders of internal-combustion engines will encounter a good many new problems. Fortunately the present knowledge of fuels for internal-combustion engines, the knowledge of the engines themselves, and above all present methods of studying fuel are so advanced that it will not take the automobile industry long to build engines to use any liquid hydrocarbon fuel such as would be at all possible to use in internal-combustion engines. This, of course, is a possibility only, but one of such wide implications outside the motor industry as to deserve mention (for example, transportation of coal in a gaseous state through pipe lines).

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Passenger Trailers

Whether trailers come under the head of housing or transportation may be debatable. That this is a rapidly growing industry of large possibilities and wide social implications, however, is beyond argument. Probably 50,000 tourist-type trailers were manufactured in 1936 and production is notoriously far below the demand.

Although ranging in price from about $200 to $4,000, the average passenger trailer probably sells for somewhere in the neighborhood of $600 or $700, accommodates two or four people, and weighs about a ton. Whether, as Mr. Babson is credited with saying, half of the population of the United States will be living in trailers within the next 15 or 20 years, or whether the trailer is mostly a substitute for a cabin at a tourist camp, an auxiliary service for our motoring population, the tourist trailer undoubtedly answers a great many demands both for mobile residences not affixed to real estate, and for cheaper and more comfortable travel.

The commercial use of trailers to display merchandise is barely in its infancy. Quite probably the use of commercial trailers in connection with the actual sale of goods or services will increase steadily, and this is a feature that may even touch the operation of large department stores and mail-order houses.

The logical development of the trailer industry would seem to be closely allied with the automobile industry. This does not necessarily mean that the automobile companies themselves will build the trailers, but distribution of this type of equipment through the usual retail automobile channels seems to offer so many advantages and to be so nearly identical in things like customers' demands for financing and trade-ins, opportunity for standardization, and chances to sell cars and trailers together, that development of separate distribution systems for trailers appears unjustifiable.

Busses

The part played by busses in passenger transportation has been shown to be relatively small; moreover, a large number of intercity bus lines are owned by railroad companies. These railroad-owned busses frequently operate on roads paralleling the carrier's own rails, or in a nearby territory, and sometimes far beyond the carrier's lines—the Burlington Railroad, for example, operates a bus service on the west coast.

The recent formation of National Trailways for the coordination of transcontinental bus schedules, for improvement of stations, and for support of an advertising campaign, involves a number of railroads which are concerned in this enterprise through their subsidiary bus lines.

In a general way, busses provide more frequent and flexible service in light traffic territories than railroads are able to do. Certainly without plenty of passengers no road can maintain track and operate trains with an engineer, fireman, conductor, and brakeman in successful competition with a bus operated by one driver and running on a public highway.

Where busses parallel railroad operations—as between Chicago and Detroit, for a conspicuous example—travel seeks the bus largely on account of cheaper rates.

In his passenger traffic report the Coordinator said:

> To meet present-day travel requirements, carrier service should be safe, easy to procure and use, attractive, characterized by sincere and warm-hearted hospitality, well rounded and complete in every detail * * *, convenient to use and unhampered by annoying routines, as comfortable as the traveler's own home, and, finally, spotlessly clean and sanitary.

How far this is a description of the average journey by bus can best be determined by the individual reader's experiences.

Granted equal rates, the busses possess many advantages for local service but, in view of the high standards suggested by the Coordinator, do they have any advantage over the railroads on long-haul services?

Evidently this is an auxiliary and supplemental service which is working out to the decided benefit of the public and to no detriment of other common carrier forms of transportation; indeed, bus lines take the place of all branch lines and light traffic lines in bringing to railroad rails a certain amount of passenger traffic which otherwise would move by private automobile for longer distances.

Motor Trucks

Over 3½ million motor trucks are registered in the United States. Their capacities may best be judged by the production figures for the past 7 years.

The table clearly shows that light trucks predominate, although it does not indicate to what extent they may be overloaded. Speed and particularly facility of operation are high factors in commercial highway transportation.

Percent truck production by capacities[1]

	1929	1930	1931	1932	1933	1934	1935
¾-ton or less	17.1	24.0	25.2	32.3	27.6	28.6	37.4
1-ton and less than 1½-ton	9.5	5.2	1.1	.6	.2	.4	.5
1½-ton and less than 2-ton	63.4	61.7	66.6	58.8	63.7	62.9	56.0
2-ton and less than 2½-ton	3.4	2.7	2.0	3.1	4.4	4.3	3.3
2½-ton and less than 3½-ton	4.1	3.8	2.7	2.4	2.2	1.9	1.4
3½-ton and less than 5-ton	1.0	1.0	1.0	1.1	.8	.8	.4
5-ton	.3	.2	.2	.6	.2	.2	.4
Over 5-ton and special types	1.2	1.4	1.2	1.1	.9	.9	.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Compiled by Automobile Manufacturers Association.

Based on the foregoing table, the average truck has a capacity of about 1¾ tons, and the 3,511,000 trucks registered in 1935 had an aggregate capacity of about 6 million tons.

In estimating the influence of trucks on railroad freight service it should be noted that the freight-carrying car capacity of the railroads is over 105 million tons, or about 17 or 18 times the aggregate capacity of all trucks in the United States. It should also be borne in mind that a large portion of the motor trucks is used for city delivery service and on farms—more than three-quarters of all trucks being Chevrolets, Dodges, or Fords—and none of this service being competitive with the railroads.

At the same time the influence of the truck is not to be minimized. Forty-eight percent of livestock receipts in 17 leading markets, 56 percent of egg receipts at Chicago, 98 percent of milk moving to 19 principal cities, large quantities of fruits and vegetables, furniture, rubber tires, short-haul coal, grain and grain products, bakery goods, and, of course, automobiles themselves, and, particularly, general merchandise, are all large items of truck traffic.

Furthermore, truck operators are, to a large extent, selective as to the commodities they handle—they do their best to skim the cream. In the past few years, where the production of heavy durable goods has fallen off so markedly, the inroads made by trucks have been more serious than they would have been under normal conditions.

In a general way trucks may be said to go after revenue rather than tonnage; to seek finished and manufactured materials rather than raw materials; and to handle consumer goods rather than capital goods.

A questionnaire of the Federal Coordinator to determine why shippers selected trucks in preference to railroad service gave the following results. (In most

cases more than one reason for using trucks was given, hence the percentages below do not total 100).

	Percent
Store door delivery	65
Faster service	65
Cheaper total cost	53
Store door pickup	51
More flexible service	43
Cheaper packing	21
Late acceptance of shipments	21
Simpler rate classification	16
Less loss and damage	11
Personal interest or friendship	3

A department store in New York may ascertain from the Weather Bureau Friday afternoon that Saturday will probably be a rainy day. In the Saturday morning papers the store will advertise a special sale of overshoes and rubber coats, telephoning a manufacturer, probably 150 miles away, Friday afternoon to furnish the sizes and styles desired. The shipment is loaded out that night in trucks and delivered at the store's door early enough the next morning to permit display before the advertised hour of the sale. Such a direct, speedy, personalized service is more than the average railroad can offer.

Ordinarily a railroad has to run trains to suit the convenience of a community and not the individual desires of some particular shipper.

A tabulation of comparative overall speeds of railways and highways, taken from the Freight Traffic Report of the Federal Coordinator, is shown.

Table of comparative speeds—rail v. highway[1]

Mileage range	Elapsed hours				
	United States	East	South	Northwest	Southwest
Under 50 miles:					
Average haul	33	33	31	31	32
Highway	4	4	3	3	3
Railway	28	30	26	22	17
Between 50 and 100 miles:					
Average haul	80	80	78	82	79
Highway	9	9	5	7	8
Railway	33	35	31	24	20
Between 100 and 200 miles:					
Average haul	156	157	149	155	154
Highway	13	14	10	10	9
Railway	38	43	32	26	27
Between 200 and 300 miles:					
Average haul	259	260	255	261	253
Highway	18	19	20	14	13
Railway	45	48	58	33	35
Between 300 and 500 miles:					
Average haul	396	393	373	399	414
Highway	27	28	29	23	24
Railway	57	63	64	44	49
Over 500 miles:					
Average haul	781	767	674	813	875
Highway	51	59	52	35	46
Railway	85	91	96	74	74

[1] Based on freight traffic report of Federal coordinator.

Comparative time—distances of rail and truck

LENGTH OF HAUL

Elapsed hours	United States		East		South		Northwest		Southwest	
	Railway	Highway	Railway	Highway	Railway	Highway	Railway	Highway	Railway	Highway
6	7	56	7	45	7	97	9	97	11	61
12	13	119	13	132	14	185	17	178	23	232
18	20	263	20	247	21	235	26	325	70	349
24	24	356	26	330	27	313	60	409	135	418
30	34	445	33	412	75	395	242	706	169	523
36	149	534	82	494	167	474	290	847	261	689
42	240	644	153	584	187	550	383	988	301	804
48	275	736	259	621	214	629	437	1,129	402	919
54	377	828	291	698	239	707	492	1,271	453	1,034
60	419	920	380	776	350	786	663	1,412	503	1,149
66	758	1,012	418	853	385	865	729	1,553	781	1,264
72	827	1,101	456	931	420	943	796	1,694	852	1,379
78	895	1,197	659	1,009	547	1,022	862	1,835	924	1,494

Much of what has previously been said as to the general nature of freight traffic in the future has special bearing on the truck situation. If with little or no increase in ton-miles traffic gradually shifts from heavy commodities to lighter ones; from longer hauls to shorter; with emphasis on speed and flexibility rather than on the carrier's operating convenience, we are facing a situation where the trucks will obtain more and more short-haul business, and particularly business where terminal handling at origin and destination are important.

Factors limiting truck operation will be public outcry against highway congestion with its attendant delays and accidents to private vehicles, an increasing demand from the shipper for financial responsibility of the truck operator, higher labor costs, higher taxes based partly on wear and tear occasioned by heavy trucks on the highways, but probably more generally based on ability to pay, and, of course, limitation of hours of service and the various sorts of regulation which are indicated in the Motor Carrier Act of 1935 and legislation which will probably grow from this seed.

A tabulation of State restrictions on motor vehicle dimensions and the recommendations of the American Association of State Highway Officials, are appended.

Gross Weight, Dimensions, and Speed for Vehicles Operating on the Highways

RECOMMENDED BY AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS

What is recommended (maximums)[2]

Width.—Eight feet.

Height.—Twelve feet six inches.

[2] Special permits required for occasional movements of materials exceeding dimensions provided.

Length.—Single vehicle,[3] 35 feet.

Combinations (only two units allowed), 45 feet.

Speed.—Minimum: Not so slow as to impede or block normal and reasonable flow of traffic except when necessary for safety.

Maximum: No bus or truck greater than 45 miles an hour; passenger automobile speeds shall be consistent with safety and proper use of the roads.

Solid-tire vehicles maximum speed set at 10 miles an hour.

Axle and wheel loads:	*Pounds*
Axle load equipped with solid, cushion, or high-pressure pneumatics	16,000
Wheel load	8,000
Low-pressure pneumatics, wheel load	9,000

State Restrictions on Motor Vehicle Dimensions

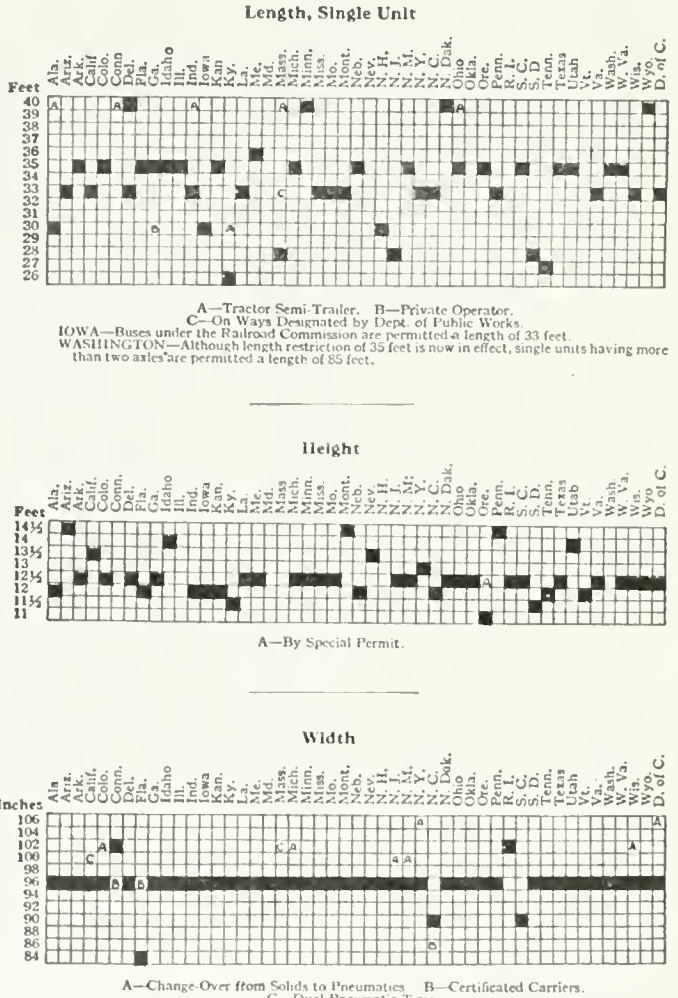
Length, Single Unit
Feet
40
39
38
37
36
35
34
33
32
31
30
29
28
27
26
Ala. Ariz. Ark. Calif. Colo. Conn. Del. Fla. Ga. Idaho Ill. Ind. Iowa Kan. Ky. La. Me. Md. Mass. Mich. Minn. Miss. Mo. Mont. Neb. Nev. N. H. N. J. N. M. N. Y. N. C. N. Dak. Ohio Okla. Ore. Penn. R. I. S. C. S. D. Tenn. Texas Utah Vt. Va. Wash. W. Va. Wis. Wyo. D. of C.
A—Tractor Semi-Trailer. B—Private Operator.
C—On Ways Designated by Dept. of Public Works.
IOWA—Buses under the Railroad Commission are permitted a length of 33 feet.
WASHINGTON—Although length restriction of 35 feet is now in effect, single units having more than two axles are permitted a length of 85 feet.
Height
Feet
14½
14
13½
13
12½
12
11½
11
A—By Special Permit.
Width
Inches
106
104
102
100
98
96
94
92
90
88
86
84
A—Change-Over from Solids to Pneumatics. B—Certificated Carriers.
C—Dual Pneumatic Tires.
ARKANSAS—Law provides that "vehicles now in operation which by reason of the substitution of tires" *exceed 96 inches*, may be operated.
NEBRASKA—The law now provides that width restriction of 96 inches may be exceeded in the case of change-overs from solids to pneumatics.

FIGURE 33. From Motor Truck Facts.

[3] Truck tractor and semitrailer construed as single vehicle in determining lengths.

Gross weights.[4]—Subject to the limitation imposed by the recommended axle loads no vehicle shall be operated whose total gross weight, with load, exceeds that given by the formula

$W = c$ (L plus 40), where—

W = total gross weight, with load, in pounds.

c = a coefficient to be determined by the individual States.

L = the distance between the first and last axles of a vehicle or combination of vehicles, in feet.

A value of 700 is recommended for c as the lowest which should be imposed, but this should not be construed as inhibiting greater values.

Why recommended

(*a*) To establish one of the fundamental prerequisites of highway design.

(*b*) To promote efficiency in the interstate operation of the motor vehicle.

(*c*) To secure safety in highway operation.

(*d*) To remove from the highways undesirable equipment and operations.

(*e*) To stabilize on a definite basis the many relationships between the highway and the motor vehicle.

Groups which have approved recommendations

American Automobile Association.
Automobile Manufacturers Association.
Detroit Board of Commerce.
National Association of Motor Bus Operators.
National Grange.
National Highway Users Conference.
National Transportation Committee.

Present regulations on size and weight compared with recommendations

NUMBER OF STATES WITH MAXIMUM

	Larger	Same	Smaller
Width	2	44	3
Height	14	23	12
Axle load	18	13	18
Length, single	10	17	22
Length, combination	26	13	10
Length, tractor semitrailer	35	7	7

(From Motor Truck Facts.)

That the trucks will achieve a virtual monopoly of short-haul business, not involving unusual sizes or weights, seems probable: how far highway transport may go beyond the short-haul zone is considered in the section of this report devoted to railroads.

[4] This gross weight recommendation is particularly applicable to bridges since axle loads and length limitations are determinative in their practical application.

Water-Borne Transportation

The history of the settlement and development of the United States before 1840 depended largely on waterways. Even before the Revolution, the Ohio and Mississippi Rivers carried an important trade with the eastern seaboard through New Orleans. Canal transportation, which reached its highest point of development in the fifties, with about 4,500 miles of routes, later supplemented coastwise, lake, and river traffic.

The United States Board of Engineers for Rivers and Harbors says that the Federal Government began to aid in the improvement of rivers and harbors as early as 1789, and the first river and harbor bill was passed in 1823. Quoting from an exceptionally able special report prepared by the Board:

The principal systems are the Great Lakes, together with the New York State Barge Canal and the Hudson River; the Mississippi River system, including the Mississippi, the Missouri, the Ohio, the Illinois to Chicago, and their important tributaries: The rivers of the Atlantic and Gulf Coasts and the intracoastal waterway system extending from Boston to Miami and from Pensacola via New Orleans down the Texas Coast to Corpus Christi, connecting with the numerous southern Louisiana waterways and with the Mississippi River system; the San Joaquin-Sacramento system in California; the Columbia system in the Northwest; and the smaller Pacific Coast rivers. These are improved or in the course of improvement over stretches and to depths commensurate with their commercial importance and with the benefits to be derived from them.

The location of the principal waterways under improvement by the United States as well as State, foreign, and privately owned waterways, is shown on the accompanying map, together with a graphic presentation of completed and projected depths.

Mississippi River System

For over a hundred years the Federal Government has had under study and improvement the Mississippi River and its tributaries. This system of waterways drains an area of approximately 1,239,000 square miles and the basin includes all or portions of 31 states. The distance by river from the headwaters of the Missouri River to the mouth of the Mississippi is about 4,200 miles. The system includes more than 9,000 miles of navigable waterways. Work already completed and authorized will provide a 9-foot navigable channel from the mouth of the Mississippi to St. Paul. On the Ohio River, a project recently completed provides 9-foot navigation from Pittsburgh to Cairo. The Monongahela, Allegheny, Kanawha, Kentucky, Cumberland, and Tennessee, feeders to the Ohio, are all under improvement. The Missouri River is navigable from its mouth to Fort Benton, a distance of 2,285 miles. Work is under way to secure a permanent navigable channel 6 feet deep, from the mouth to Sioux City, Iowa. Farther to the south are the White, the Arkansas, the Red, the Ouachita, and other tributaries of minor importance, each of which is under improvement. The Illinois waterway, forming a link between the Mississippi system and the Great Lakes, provides a channel depth of 9 feet.

Flood control works on the Mississippi River and on outlets and tributaries affected by the back waters of the Mississippi have been prosecuted where the local contributions for such work required by law have been provided. Dike construction and revetment works to stabilize the navigable channel have been prosecuted and are being continued. The Fort Peck dam and reservoir project, in addition to providing a low water supply for the Missouri River, will materially aid in the reduction of flood damages, create a large output of cheap power, and provide water for irrigation purposes. This project was 19 percent completed at the close of the fiscal year 1935.

MOVEMENT OF PRINCIPAL BULK COMMODITIES ON THE MISSISSIPPI RIVER SYSTEM, 1919–1934

FIGURE 34.

Ninety percent of the traffic on the Mississippi system is bulk commodities, the nature and volume of which in recent years are shown by the attached graph.

Measuring freight service by ton-miles the division between the various inland waterways, excluding the Great Lakes, is as follows:

	Percent
Mississippi River system	67
Canals and connecting channels	16
Atlantic coast rivers	11
All other	6

The Great Lakes

With a shore line of over 8,300 miles and a water surface of over 95,000 square miles, the Great Lakes and their connecting channels form one of the world's most efficient transportation highways.

Again quoting from the United States Board of Engineers' report:

From Montreal, which is at the head of deep-draft ocean navigation on the St. Lawrence River, the sailing distance to Duluth at the head or westerly end of Lake Superior is about 1,340 miles, and to Chicago at the head of Lake Michigan about 1,250 miles. About 975 miles of the Duluth distance and 950

miles of the Chicago distance are in the open lakes. In the connecting rivers and ship channels which govern navigation between Lakes Ontario, Erie, Huron, Michigan, and Superior, the available draft is at least 20 feet; the only canal locks are in the Welland Ship Canal and in St. Marys River near Lake Superior, and they afford a usable length of 859 feet and width of 80 feet. There is available by way of the St. Lawrence River a navigable channel from Lake Ontario to Montreal having a depth of 14 feet. The New York State Barge canals afford free waterway communication between Lakes Erie and Ontario on the west and the Hudson River and Lake Champlain on the east, providing a channel depth of 12 feet.

In all there are approximately 100 United States harbors on the Great Lakes and connecting channels, of which about 80 are of sufficient importance to warrant improvement by the Federal Government. The more important harbors on the Great Lakes have facilities and railroad connections for handling through traffic in addition to local commerce. The commerce of the smaller ports consists mainly of receipts of coal and supplies for local consumption and shipments of lumber, plywood, etc.

The size of the lakes, divided as they are by narrow channels, and the enormous volume of bulk freight to be transported in a limited navigation season created a demand, the response to which is the modern bulk freighter. These vessels are constructed to standards which permit of greatest efficiency in loading and discharging, and the typical long, low construction gives a tremendous carrying capacity on a shallow draft. The self-unloaders, a type of carrier originating on the lakes in 1909, were designed to meet the demand for carriers of stone, coal, sand, and gravel, to ports where there are no adequate facilities for discharging. These boats can go to any port having sufficient depth of water to receive them and discharge cargo by means of an endless belt conveyor running beneath the holds to a bucket conveyor lift, which in turn carries the commodity to the discharging boom at the bow of the vessel. These booms are capable of lifting the cargo to a height of 65 feet above the ground and depositing it 115 feet from the side of the vessel.

Traffic on the Great Lakes consists mostly of grain down-bound and a balanced traffic in iron ore down-bound and coal up-bound. Over three-quarters of the iron ore produced in the United States is handled from upper lake ports to Chicago and Gary on Lake Michigan, to Detroit, and to the lower Lake Erie ports principally for transshipment by rail to interior furnaces in Ohio and Pennsylvania.

The big share of the domestic production of grain goes from the upper lake ports to Buffalo for movement east by rail or through the barge canal. Canadian grain moves chiefly via Montreal or Quebec.

Coal from Pennsylvania, Ohio, West Virginia, and Kentucky moves by rail to Lake Erie ports, thence by water to the head of the lakes and admirably balances the down-bound ore tonnage—in fact in recent years it has somewhat overbalanced it.

In addition to superb natural highway and highly developed vessels, the Great Lakes have ample dock facilities, grain elevators with great storage capacity, ore shipping docks up to half a mile in length with unloading machinery capable of handling 2,500 tons an hour, car dumpers for handling coal, dry docks, marine railways, warehouse facilities, ship channels, and harbors generally more than adequate.

The efficiency of this transportation system places it beyond competition during the season when the lakes are free of ice, and in this season can be handled most of the year's traffic.

FIGURE 35. View of ore dock, Duluth, Minn.

FIGURE 36. Federal barge line tow leaving New Orleans.

Coastwise Traffic

Coastwise traffic includes movements between any two ports on the Atlantic, Gulf, or Pacific coasts. During the year 1934 over 100 million tons of this business were handled, representing a value of over 4 billion dollars. The most important movement is from the Pacific Coast to the east, made up mostly of canned goods and lumber. About 90 percent of the intercoastal trade, exclusive of oil-tanker traffic, is handled by common carriers, while most of the tank ships are industrial carriers.

Under the Panama Canal Act of 1912, now embodied in section 5 of the Interstate Commerce Act, railroads may not own, lease, operate, control, or have any interest directly or indirectly in any common carrier by water with which the railroads compete or might compete.

Panama Canal

The Panama Canal has been responsible for marked reductions in water rates between the east and west coasts of the United States. This has diverted a great deal of transcontinental traffic from the railroads and generally been to the advantage of the seaboard communities and their contiguous territories, to the detriment of the Middle West. Most of the territory east of the Alleghenies using land transportation to or from the seaports in connection with water transportation between the Atlantic and Pacific coasts, has profited at the expense of the Mississippi Valley communities. Naturally this has had a far-reaching effect upon the navigation of inland rivers.

The principal items moving through the Panama Canal from the Pacific to the Atlantic are grain and grain products, refined oils, sugar, lumber, fruits, crude oil, copper, vegetables, paper and pulp, fish and canned goods. Westbound iron and steel, general merchandise, cotton, metals, lubricating oils and greases, phosphates and sulphur are important items.

About 20 percent of the entire Panama Canal traffic is handled in tank steamers, and ever since the Canal has opened the preponderance of trade through it has been between the Atlantic and Pacific Coasts—east-bound traffic predominating in about a 3 to 1 ratio.

Intracoastal Waterways

The Federal Government has gradually built up an intracoastal waterways system consisting of a series of natural and artificial water courses reaching from Cape Cod Canal, Mass., to Miami, Fla., and from Apalachicola, Fla., to Corpus Christi, Tex. With the exception of about 100 miles between Cape Fear River and Winyah Bay, light draft vessels have a continuous

route from Trenton, N. J., to Miami, Fla. Along the Gulf Coast are 669 miles of inside waterways with 9-foot channels, and about 300 miles of shallower and incomplete sections. It is impracticable to determine the net water-borne commerce of these intracoastal waterways, although records for isolated sections show a general tendency to increase in volume.

From 1920 to 1929 water-borne commerce in the United States increased steadily, and since 1929 has probably fallen off less rapidly than rail traffic.

Studies made by the United States Board of Engineers for Rivers and Harbors tend to show, based on tonnage alone, that freight transportation by water was about 17 percent of rail tonnage in 1920, gradually rose to 30 percent of rail tonnage in 1933, and only slightly receded in 1934. Both agencies lost traffic to highways and pipe lines during the period.

Future Developments

Looking to the future in waterway transportation, no radical changes are in sight. Use of the Diesel engine on inland waterways and smaller coastwise vessels is progressing. On inland waters the tunnel type propeller boat is supplanting the old-time stern paddle wheel Mississippi River steamer. The preceding photograph of a Federal barge line tow leaving New Orleans illustrates the exterior of this type of boat. The after portion of its hull is in effect divided by a tunnel, arch, or egg-shaped recess in which the propeller operates submerged in water but projecting at most only a short distance below the level of the ship's bottom.

A good deal of attention has been given to the development of inland waterway propelling craft suitable for low-bridge clearances. The use of welded construction for steel hulls is gaining, reducing cost and dead weight, eliminating rivet points and lap edges of plates and materially reducing skin friction. This applies particularly to smaller vessels, including river craft.

On the large coastwise boats and in overseas trade, both Diesel engines and high-pressure-steam turbines are increasingly important factors. The Director of the United States Shipping Board Bureau states that the principal advance in technical shipping developments in recent years has been in fuel economy. This has resulted from the adoption of air preheaters and economizers, a steady increase in boiler pressures and temperatures which now run about double standards which prevailed at the close of the World War, and more modest improvements in the steam turbines.

We cannot yet be sure whether marine power plants will be Diesel or steam—the steam plant having a marked advantage in the price of boiler fuel, in weight, simplicity, and generally in initial cost, the Diesel having a somewhat lower oil consumption per horsepower.

Improvements other than those to propulsive machinery include specially designed propellers and rudders, and stream-lined after hulls to improve the flow of water to the propellers.

While Van Loon's contention that in thousands of years of shipbuilding the only vital changes have been from manpower to sails and from sails to machinery is perhaps extreme, water transport is almost the oldest of all forms of transport. As such, it can hardly look forward to the rapid developments of newer agencies such as airplanes. Nor is any spectacular development in sight for a form of transport so largely devoted to handling bulk commodities. While Florida fruits and vegetables may move by water to eastern markets, deckloads of automobiles be shipped on the Great Lakes and the Mississippi River, merchandise move freely from the Atlantic seaboard to Texas, and many other kinds of traffic obtain sufficient service as well as low rates by water, the general characteristics of water transportation are not speed and flexibility. Where port-to-port business in sufficient quantities is available, commerce will take to the water like the proverbial duck. When, however, it is necessary to gather freight at interior points, move it by rail or highway to a waterway, transfer it to a vessel and repeat the process at the other end, speed, flexibility, and even costs are unfavorable, although a certain amount of such business moves on lower than all-rail rates.

Probably inland waterway traffic, both from its nature and the competition of other transportation agencies, will increase much slower than coastwise traffic. Business on the Great Lakes is almost as specialized as that of the pipe lines and has long been so well developed and so efficiently handled that no great fluctuations are probable.

Railway Transportation

Motive Power

In 1936 the class I railroads owned 45,000 locomotives, over 98 percent of them being steam engines. Over 60 percent of the railroad locomotives are more than 20 years old.

Looking to the future three types of railway motive power will probably be used—electric, Diesel, and steam.

The recent electrification of the Pennsylvania-New York-Washington lines, including particularly the great terminals in New York and Philadelphia, less recently the electrification of the Illinois Central suburban zone out of Chicago and the N. Y. C. electrification of the Cleveland terminals, together with the older

electric lines of the New York Central and the New Haven out of New York, have given millions of people personal experience with this form of transportation. Invariably they are impressed with the electrified road's rapid acceleration, smooth operation at high speeds, cleanliness, and ability to handle anything from the smallest switch locomotive or single unit passenger car to the longest, heaviest, and fastest freight and passenger trains.

Railroad electrification, however, is the result of necessity rather than desire. This necessity probably arises first in the operation of congested terminals, particularly where on account of tunnels (New York is the most conspicuous example) no form of combustion locomotive can be used. Popular demand for smoke elimination is a factor, but an electrified terminal's ability to handle traffic beyond the economical and often beyond the possible capabilities of steam equipment is the principal reason.

Main-line operation with electric locomotives plainly has many advantages once terminals are electrified. Here again the justification of electrification rests far more on density of traffic than on any other factor.

Electrification involves a heavy additional investment, probably creating little additional traffic. Only with a large volume of business can enough operating expenses be saved to justify the increased capital charges. Broadly speaking, a railroad line will have to double its capitalization in order to electrify. It is true that the electrified road will cut its coal bill in two and effect other less striking operating economies, but obviously the new capital costs must be spread over a tremendous volume of freight and passenger business.

Occasionally exceptional operating conditions may force electrification. The Norfolk & Western handles heavy tonnage trains on mountain grades running up to 2 percent; the Swiss railways operating on steep grades and through many long tunnels in a land possessing unlimited hydroelectric power and no coal whatever, are cases in point. Regenerative braking is a favorable factor under these conditions.

Railroads directly serving coal mines and those whose tonnage is largely coal will not be eager to electrify as a matter of general business policy, though so great a coal carrier as the Pennsylvania has been forced to do so by special conditions.

In the United States electrification will, therefore, be confined in the main to extremely dense traffic areas. The Pennsylvania will probably extend both its passenger and freight lines from Paoli and Trenton to Harrisburg. If passenger traffic further develops it is possible that the New Haven may some day extend its electrified lines to Boston. Based on current traffic density, the main line of the New York Central presents some possibilities for electrification, although it seems improbable the necessity for such action will arise in the next 10 or 15 years.

Quite recently the Diesel engine, as the motive power of lightweight high-speed streamlined trains of novel designs and colors, has received wide attention.

Despite high thermal efficiency, the advantages of Diesel power as compared with steam locomotives for road passenger service remain to be demonstrated. The present Diesel locomotive is, roughly speaking, a mobile electric power plant. The Diesel itself, like any other internal combustion engine, converts the heat energy of its fuel into mechanical energy; the mechanical energy is then transformed through an ordinary generator into electric energy; this electric energy is turned back into mechanical energy through motors geared to the wheels. Most of this conversion and reconversion of energy and the investment in electrical equipment merely serves as a substitute for what would be a clutch and a transmission in an automobile.

While the Diesel engine in passenger service will attain a high degree of reliability and simplicity; while it will require little time in the shops; while little operating time will be spent in fueling, taking water, etc.; and the engine will generally be economical to operate, these advantages are today largely nullified by high investment costs and fixed charges. Such costs will no doubt be reduced, and if safety and other considerations will permit the crew of a Diesel road locomotive to consist of a smaller number of men, or be paid less than a steam-locomotive crew, material reductions in operating costs may be effected.

For long-distance operation at sustained high speeds the Diesel has the advantages of carrying an ample supply of fuel and water and being relatively easy on the track, just as is the ordinary electric locomotive, due to freedom from "hammer blows" set up by reciprocating parts employed in steam locomotives and not used on an electric engine.

Based on about 10 years' actual operation in Europe and extensive experiments and tests in the United States, supercharging of Diesel engines is just getting under way in this country. The engine builders are seeking to recover power from the exhaust gases in sufficient amounts to drive the supercharger and hope thus to obtain a material increase in power without a corresponding increase in the dimensions of the Diesel engine itself. Where space and weight limitations are desirable, as in railroad service, developments along this line are logical. Increases from 30 to 80 percent in power are talked about and one manufacturer is actually guaranteeing 900 horsepower from an engine customarily rated at 600 horsepower.

Even today the Diesel electric has many advantages in terminal service, and in that field probably lies the Diesel's best chance in the near future. Particularly

will this be true when electric transmissions cost less or if less costly hydraulic or mechanical devices are developed. The average switch engine spends the majority of its time doing nothing except burning coal; the Diesel engine can be shut off and started about as easily as the ordinary automobile. Public outcry against the noise and smoke of steam switch-engine operation can be satisfied by Diesel operation. Cold weather, to which so many of our greatest railroad gateways and terminals are exposed, cuts about a third off the power of steam locomotives and does not affect Diesels.

The Diesel electric switch engine generally has a higher starting power and better acceleration than corresponding steam engines, does not have to haul a 50- or 60-ton tender wherever it goes, can operate more than 48 hours continuously without taking fuel or water, and naturally does not require fire cleaning and boiler washing.

The principal limit on Diesel switching today is probably the railroads' unwillingness in the face of decreased business to retire existing steam power, much of which has nearly been written down to a scrap basis, and incur the relatively heavy capital charges involved in new Dieselized equipment.

Looking forward to a freight traffic increasing only slowly at best beyond the 1926–28 levels, the bulk of railroad freight will be hauled by steam locomotives. Indeed no serious effort has been made to apply Diesel power to freight service other than switching or transfer service, and little or no doubt is expressed as to the steam locomotive's ability to meet any ordinary demands of freight or passenger service. Considering the many years of research and practical experience back of steam engineering, and the cumulative and accelerating progress in this art, this is to be expected. Nor does this imply any lack of progress. Few types of machinery have been so greatly improved in the past 20 years as steam locomotives. Weight per horsepower has been cut in half and the thermal efficiency doubled. Progress in the future will undoubtedly continue. Higher boiler pressures, higher steam temperatures, greater fuel economy, greater steam capacity, better steam distribution, ability to make longer daily runs and greater mileage between shoppings—in all these and many other ways the steam locomotive is being so radically improved that comparatively few people realize the superiority of today's locomotive over engines built 15 or 20 years ago.

Even for light streamlined trains, where popular demand seems to be for novel shapes and colors of motive power, the reciprocating steam locomotive, considering particularly its cost, offers about as much promise as the Diesel. An exception is on long runs where, making seven or eight hundred miles a day at sustained high speeds, a Diesel can show operating economies outweighing its heavier investment costs.

Lighter weight, lower maintenance, greater efficiency and economy, construction with more steel castings and more welding, and, of course greater durability and higher speeds, are constant trends in the steam locomotive's construction.

The steam locomotive will likely prove adequate to the general demands of the railroads in the next 20 years, and in the field of passenger traffic will help to bring to the rails a good share of the business now handled by other agencies.

A great deal of thought has been given to the possibilities of steam turbines instead of the reciprocating steam locomotives as universally used in this country.

Steam turbines and Diesels have the common disability of being relatively constant-speed machines (the Diesel less so) and, therefore, involving the complications, expense, and weight of some form of flexible communication between the engine and the wheels. At present, the electric transmission is favored. With potential competition from mechanical, hydraulic, or pneumatic drives, and with an expanding market, the present costs of electrical transmissions can, undoubtedly, be materially reduced.

Just as a notable advance in automobile power plants have been secured by building light high-speed engines, the steam turbine—preeminently high-speed machinery—has an excellent ratio of horsepower to weight. The principal difficulties in the development of this type of locomotive have not arisen from the turbine itself, but in the attempt to get a compact condenser and from the auxiliaries of the condenser, such as the pumps.

While more attention has been given the development of turbine locomotives in Germany, Great Britain, and Sweden, than in this country, the General Electric Co. are now building a 5,000 horsepower locomotive (made up of two 2,500 horsepower self-contained units) for the Union Pacific Railroad, and this engine, according to disinterested expert opinion, will prove satisfactory.

This type of locomotive is, of course, designed for long-distance, high-speed, nonstop passenger service, in which field the Diesel electric is also seeking to establish itself. Both types, with their electric drive obviating counterbalanced driving wheels, side rods, and similar reciprocating parts, their excellent balance, and high maximum speeds with relatively little damage to track structures offer a good deal of promise. Maintenance costs on both types are problematical, as is the all-important factor of reliability. It is noteworthy that both the Diesel and the steam turbine are extremely reliable in stationary service.

Track

Not only will passenger trains frequently be operated at speeds above 70 miles an hour, but many freight trains will be run about two-thirds of passenger speeds. Much freight today is handled on schedules comparable with passenger-train speeds of a few years ago and the demand for such service has virtually rendered obsolete much railroad freight power. Plainly, however, the use of higher train speeds depends essentially on railway location and track.

Improvements in grade, alignment, and roadway and track structure will be necessary; signal locations will have to be changed, and passing-tracks relocated in many instances. A higher standard of track maintenance will generally be required to prevent passengers losing in comfort what they gain in speed.

Freight Cars

With 2 million freight cars in service it is plain that changes in this class of equipment can only be made slowly.

But for the development of the motor truck we might have followed British practices and built a lot of 8- and 10-ton capacity, four-wheel freight cars such as long ago were the result of the general retail character of British freight service.

Twenty-five years ago Professor Cunningham, of Harvard University, said:

> There is, however a feeling among a few railroad men that the railroads of New England might profitably take a leaf from the notebook of Old England and experiment (1) in the collection and delivery of freight; (2) in the use of the small capacity car; and (3) in the running of express freight trains * * *. The preponderance of l. c. l. freight in New England might justify the small car and something approaching the British express freight service * * *.

With this class of traffic, however, so largely lost to the motor truck we may anticipate neither radical nor rapid changes in our freight equipment. A good deal can yet be done toward reducing weight both through changes in car design and the substitution of lighter materials. The savings, however, will be largely confined to the item of fuel, and fuel costs are now on such a low gross ton-mile basis that any car having a higher first cost will have difficulty in justifying itself. This is particularly true considering how much of the time a freight car is not in motion.

A new form of car will be worked out to carry either truck bodies or containers, but its ultimate development waits on the determination through experience as to which of these forms of rail-and-truck coordinated transportion is most satisfactory. It seems unlikely that both will have a place.

Passenger Cars

Since the introduction of steel cars over 30 years ago, no single feature of passenger equipment has had so wide an appeal to the traveling public as air-conditioning. On October 1, 1936, about 8,000 air-conditioned passenger cars were in service, being almost equally divided as to ownership between the railroads and the Pullman Co. Seventeen hundred of these air-conditioned cars had been put in service in the 6 months prior to October 1. While the cost of installing air-conditioning equipment ranges from about $4,000 up to $8,500 per car, depending on the type of equipment installed, this work is progressing rapidly.

In cleanliness, in quiet, in comfort, and particularly comfort during the summer months, air-conditioning of passenger trains has furnished the railroads with one marked advantage over all their competitors save perhaps the transport planes.

Increased speed in passenger business demands decreased train resistance. Weight reduction is an effective means to this end. It is especially important where fast schedules are required with frequent stops, as in suburban service, or where moderate speeds over heavy grades are required.

Streamlining, at least in appearance, is demanded by a public which is following the development of the airplane with a lively interest and to which even the appeal of "streamlined" electric refrigerators seem to be potent.

Considering that comparatively few passenger trains are operated dead to windward, nor can they retract their wheels and running gear and present a smooth undersurface as does the transport plane, the tangible benefits of streamlining are generally much less than is commonly believed. At speeds above 60 miles per hour, streamlining is increasingly beneficial. In the bulk of such passenger service as we have today below such speeds, it is questionable, however, whether the benefits of streamlining would exceed those of bright colors—both catch the public eye and the public fancy, and are of undoubted benefit in advertising, if not in operation.

Reduction of the cross section of a train, particularly a short train, has so far been of more tangible benefit than actual streamlining. However, where trains are operated at extremely high speeds with few stops and especially over long distances, streamlining is of material benefit.

Whether the traveling public will ultimately favor cars of less than conventional width and headroom remains to be seen—probably on such runs as from Chicago to the West coast a fairly liberal amount of room will be necessary in competition with transport planes, which already provide longer and wider berths than the standard Pullman.

Certainly, however, reduction of passenger car weights and dimensions is a promising field. The Federal Coordinator found that the net load of a passenger train was less than 4 percent of its gross weight and that the coal and water in the tender alone weighed more than the people transported. While this is an extreme statement resting on the supposition that the travel needs of human beings are comparable to those of package freight, nevertheless the present railroad passenger car weighing over a ton per foot of length is susceptible of improvement and this is already evident not only in the new streamlined cars but in coaches of more conventional design built for the Milwaukee, the New Haven, and other roads.

The Milwaukee, for instance, is rebuilding 50 coaches, using a welded instead of a riveted body and cutting the weight of the entire unit from 146,000 pounds to 96,000 pounds—a saving of 34.2 percent.

The coaches on the Burlington streamlined "Zephyrs" weigh only 55,000 pounds, and the semiconventional "Hiawatha" coaches on the Milwaukee weigh 112,000 pounds.

The Federal Coordinator concluded that the greatest need of railway passenger traffic was an efficient single-car unit capable of carrying passengers, mail and express, and operating at high speeds and low costs on branch lines, as well as giving more flexible and frequent main-line service. In this type of vehicle, however, though it is said that English and continental railroads have had some success, and the new Norfolk Southern "Railbus" equipment in this country is a really significant development, the question is largely one of traffic conditions. Where distances are short and traffic requires frequent service such 25-ton cars seating 50 or 60 people, with a crew of two men only, powered with standard bus engines and operating over the railroads' private right of way instead of congested highways have good possibilities. Such traffic conditions, however, do not prevail on any large portion of the branch-line mileage and still less on the ordinary main line of railroads in this country.

Another interesting development with a good deal of promise is the New Haven two-car train equipped with a Besler high pressure steam power plant. Using a steam pressure of 1,200 to 1,500 pounds per square inch, the space requirement and weight of the power plant are strikingly low. Its manufacturers claim that in comparison with a Diesel electric power plant, their high pressure steam system can offer a horsepower developed at the wheel for a third of the weight and a little over half of the cost. The relative initial costs of a steam plant as compared with an internal combustion engine and the adaptability of steam locomotive maintenance to existing facilities are favorable factors but, like Diesel electric or turbo-electric units, the operating economy, maintenance cost and reliability of this steam rail car can only be determined as the result of long-service operation.

A great benefit of light passenger equipment which may be cheaply operated is the resultant ability of a railroad to provide frequency of service. From the standpoint of the traveling public this is highly important.

How great an attraction frequent fast service is can be seen by anyone having occasion to travel on the hourly trains between Washington and New York or Boston and New York. While not many sections of the country develop the heavy passenger traffic available between these cities, plainly the man who can find even three or four trains a day to his destination is less apt to seek other forms of transportation than the man who has choice between a train at 3 o'clock in the morning and another at 3 o'clock in the afternoon.

It is interesting that the air lines are so fully alive to this situation—their efforts for some years have been directed toward getting single units of an economical size and then providing frequent service rather than toward getting extraordinarily large planes with relatively infrequent flights.

Branches

From 1921 to 1934, 7,100 miles of railroad were constructed in the United States, and 13,900 miles permanently abandoned—a net loss of about 3 percent spread over 14 years.

Considering the many miles of road unwisely built for competitive or speculative reasons and never justified on a commercial basis, considering also exhaustion of natural resources, and taking into account the trend of population toward stabilization, it is surprising that the net loss of railway mileage has been so small.

Railway mileage will be further reduced as time goes on, but it will be a gradual process in which each individual case will be carefully considered. Short lines, particularly those serving fields where agricultural, forest, or mineral resources have been exhausted, will probably be retired first.

Little in this situation is alarming or even novel—only a superior transportation service, or a lack of need for any transportation service, forces a road to give up a branch. So far as excessive cost of branch-line operations arises from engine and train labor—crews of five men as against one on a truck—the situation can be worked out through transfers or retirements. Maintenance costs, however, are unescapable and will prove the determining factor.

Rail Versus Highway

For reasons previously outlined, freight traffic as a whole is likely to return slowly to levels existing prior to 1930, and beyond these levels will grow even more slowly.

The graphic chart, comparing railroad freight service with various indices of general business activity, shows a remarkably close relationship over the period 1919-30 and a disappointingly slow increase in revenue ton-miles since 1930–31.

It is true that the railroads in 1934–35 originated only about 50 percent as great a tonnage of durable goods as they did in the years 1923–29, inclusive. Even assuming, however, that much of this loss in the heavy commodities will eventually be recovered, the trend shown by the chart still leaves much to be desired from a railroad standpoint.

An underlying factor of great importance arising out of stabilization of population and the settling up of large areas, is the growing commercial demand for rates and service based on something between the present less-than-carload shipments and the full carload. This demand was manifest in southern New England 25 years ago, and evidently increases as population tends to become static. The commercial requirements of many shippers are undoubtedly for smaller quantities than present railroad carload minimum weights.

Maintenance of minimum weights proportionate to the ever-increasing size of box cars and failure to establish rates based on shipments in quantities a fourth or a fifth of the full tonnage a car can handle have contributed in no small measure to the building up of motortruck traffic.

Added to this, on short-haul high-speed merchandise traffic the motortuck is in many ways definitely superior to the railroad. Ability to pick up and deliver freight, more liberal packing requirements, and a service both more speedy and far more individualized to the particular shipper's needs, are obvious to anyone dealing both with motortrucks and railroads.

The solemn progress of a few hundred pounds of freight loaded in a 40-foot box car from one small New England town to another is vaguely reminiscent of the interest of a circus elephant in a solitary peanut.

On the other hand, with heavier loads and longer hauls—in doing what would be termed a wholesale rather than a retail business—the advantage is almost entirely with the railroad. As the Federal Coordinator recently stated:

> I now see little future for long-haul motortruck haulage of most commodities, although I expect to see the shorter-haul operations expand continually.

Plainly, however, a definition of long haul is what is needed.

Mention has been made of a demand for equipment, rates, and service somewhere between the less-than-carload shipment and the full-carload shipment. It is in this zone, as well as in the zone between long-haul and short-haul traffic, that railroads and trucks are in the most intense competition.

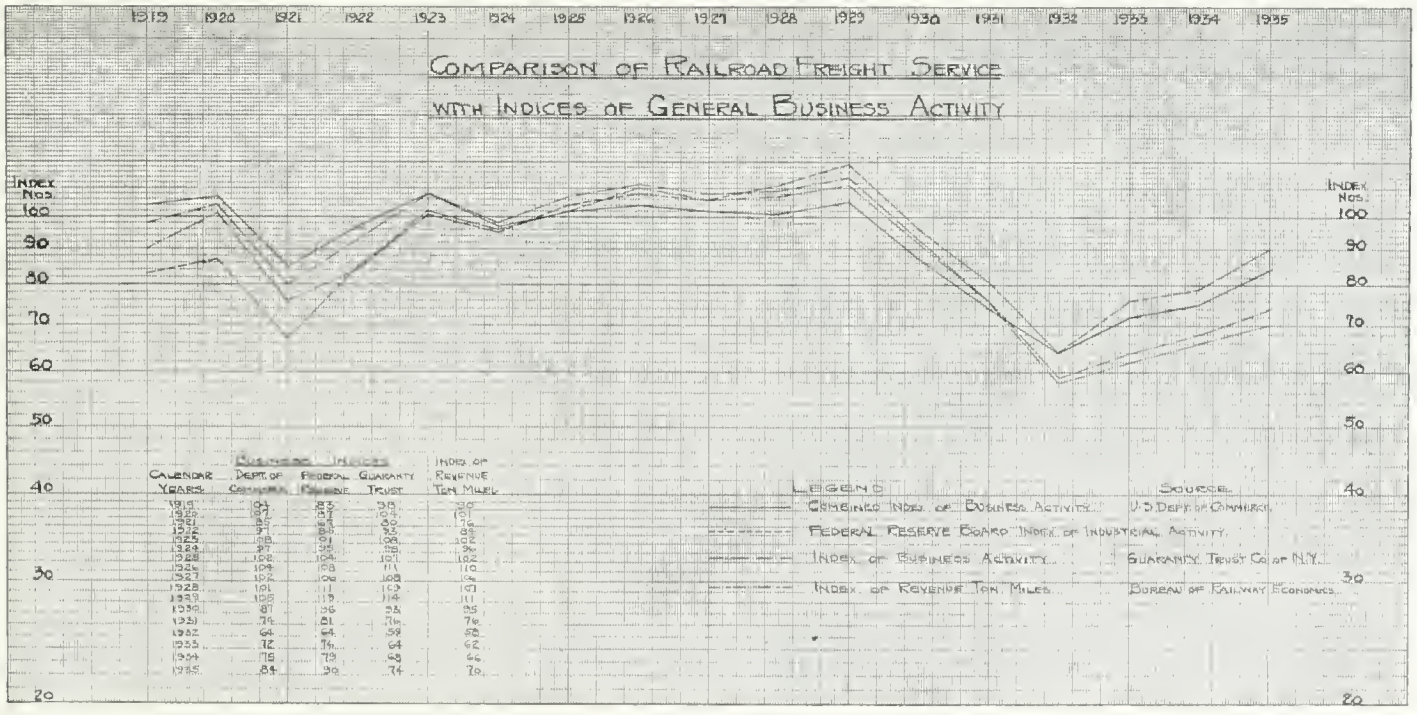

FIGURE 37.

Based partly on the old principle "If you can't lick 'em, jine 'em", and partly on the even older idea that distant pastures are always green, attempts are being made to coordinate rail and truck service. The idea, of course, is for the trucks to handle terminal operations, but for the line haul between one city and another to be handled by the railroads, keeping trucks off our intercity highways and turning over to the railroads the strictly haulage or "line" service.

Among present developments are freight containers which may be loaded by shippers, hauled to railroad freight stations, placed on flat cars and further shifted at transfer stations if necessary to provide for solid carloads of containers to a particular destination, where, in turn, the containers are unloaded and trucked to the ultimate receivers of the freight.

Or coordination may take the form of gathering freight by trucks and transporting the truck bodies themselves by rail from one city to another. If the truck haul be lengthened beyond the terminal zone, and such arrangements are ultimately found profitable and approved by public authority and public opinion, a railroad may thus invade the territory of its competitors and intensify a competition which has in many instances already been carried to unsound lengths.

Whether the trucking facilities in such cases are owned by the railroads, or whether through rates are divided between the railroads and independent trucking concerns, is probably immaterial from the public standpoint.

It should be noted, however, that no railroad, much less 8 or 10 different railroads, can possibly make arrangements of this nature with all the truck operators in New York, for instance. Whether a road owns and operates its trucks or whether it makes contracts with any reasonable number of truck operators, it seems doubtful that such a plan would fit the individual shipper (who, of course, in many cases owns his own trucks) so precisely and satisfactorily as do present arrangements. It is also a question at just what distances line-haul traffic can be more economically handled by railroads than by trucks which are already loaded for particular destinations.

Containers, of course, presuppose a rather limited number of trucking agencies, railroad-owned or otherwise, but present the same essential problem, that of cost. Incidentally, any development of container traffic will probably involve smaller units in addition to sizes which are now used.

Certainly this is a field in which prophecy should not be too positive. Probably it is enough to point out that from the standpoint of the shipper and also from that of the general public the prospects of increased flexibility, increased speed, more competition, and lower costs, are all pleasing.

Again quoting the Federal Coordinator's report:

> Whether regulated or not, the prices charged by highway or waterway operators, as well as by railways, inevitably will be limited to what it costs the shipper to provide his own service as a ceiling, and what it costs the carrier to furnish it as a basement * * *. The ability of the shipper to provide his own transportation by highway limits the operation of the value of the service principle to the cost of such owner transportation, as the maximum charge which may be imposed.

Where the Government regulation may ultimately step in to the benefit of all concerned is in preventing the trucks and railroads from cutting each others' throats. Government regulation in the past has probably saved a good many roads from attempted suicide, and this particular sort of history may quite easily repeat itself among the trucks.

Rail vs. Pipe Lines and Waterways

Just as a demand for equipment, rates, and service between less-than-carload and full carload shipments exists and is of particular importance in the competition between railroads and motor trucks, a demand for trainload or cargo rates influences competition between railroads, pipe lines, and waterways. In this respect European railroads have long had an advantage as compared with those of the United States.

Twenty-five years ago Logan G. McPherson in "Transportation in Europe" said:

> In many countries they accord a trainload rate which is even lower per ton than the carload rate. This practice is justified as an extension of the wholesale principle, of which the carload rate is the first manifestation. As the cost of moving a solid carload is less than that of carrying a number of scattered shipments of the same weight, so also the cost of moving a train of fully loaded cars, containing one commodity from one place of shipment to one destination, is less than that of moving the same number of carloads of heterogeneous contents to different places. The granting of the trainload rate, however, has been forbidden by the Interstate Commerce Commission, and its ruling was upheld by the Supreme Court of the United States on the ground of public policy.

Whether carriers today may legally maintain lower rates for traffic in 10 or more carloads than upon a single carload is doubtful. Certainly the Interstate Commerce Commission has unfailingly refused to permit the establishment of rates available only for the shipment of a trainload, holding generally that lower rates on trainload lots than on single carloads would be a condition with which only a few shippers could comply and, therefore, an injustice to those unable to ship the required quantity.

In recent years, however, the Interstate Commerce Commission has in a number of cases recognized the economy of trainload shipments as a factor in rate making, enabling the railroads for instance to meet

competition of steamers on the particular dates when vessels sail North with fruits and vegetables from Florida, and, again, to meet the situation brought about by the Seatrain Car Ferry which handles about a hundred loaded freight cars at a time from New Orleans via Havana to New York.

While accurate figures are lacking as to the extent to which cargo shipments of petroleum, grain, coal, lumber, ores, fruits and vegetables, etc., might move by rail, the totals are large.

The Federal Coordinator recommended that the railways should follow the lead of the water and pipe-line carriers in providing cargo rates, presumably based on as high as 5,000- to 8,000-ton shipments.

While comments on public policy are outside the scope of this report, it may at least be pointed out that rates on cargo shipments equivalent to 80 or 100 railroad carloads are available via pipe lines or waterways, but not by rail.

Pipe Lines

The least conspicuous, the most efficient (within its limits), and the most successful economically of all present forms of freight transportation is the pipe line.

Operations of pipe lines in 1932, as reported to the Interstate Commerce Commission, show 93,000 miles of line, 83 million tons of oil originated, and a gross investment of 764 million dollars. The total of all petroleum pipe-line mileage is probably in excess of 115,000 miles, and these lines even through recent years have, as a whole, yielded a fair return on the investment—something that can be said of no other transportation agency.

California, Oklahoma, and Texas produce over 80 percent of our crude oil: East of the Mississippi River, where 70 percent of the population and the gasoline consumption is found, only 5 percent of our oil is produced. The solution of this has been forcing oil through 8-inch or 10-inch diameter lines of pipe, and this has been done with such efficiency that even waterways offer small competition save for such long hauls as from Texas Gulf ports to New York and Philadelphia. Less than 3 percent of the production of crude petroleum is handled by railroads, about 25 percent is moved coastwise, and the remaining seventy-odd percent travels by pipe line.

Of petroleum products, however, only 3 percent or 4 percent moves by pipe line, the balance being fairly well divided between the railroads and the waterways.

The oil is pumped by Diesel engines taking their own fuel from the line, or by electric power. Steam equipment, which formerly predominated, is pretty well confined to the territory east of the Mississippi River and is a relatively minor factor. Oil moves through the lines at about 3 miles an hour, and at 325 barrels per mile of 8-inch pipe and about 500 barrels per mile of 10-inch pipe some 40 million barrels are stored underground and are practically as permanent an investment as the pipes themselves.

It may be noted that in addition to this quasi-storage in the lines the pipe-line companies and their owners, the oil companies, have about 400 million barrels storage capacity. Most of this storage is incidental to the purchasing, marketing, blending, and refining of oil rather than to its transportation.

No revolutionary developments in pipe lines are anticipated in the next 20 years, but the mileage of these lines is steadily and profitably increasing.

Exhaustion of oil supplies would, of course, upset the present pipe-line industry. Whether synthetic alcohols made from vegetable matter could be manufactured in our present oil fields or intermediate points is a problem we shall probably face during the present century but not in the immediate future. Something analogous to this has taken place in the conversion of at least one pipe line which formerly handled petroleum east-bound into a west-bound gasoline pipe line. Alcohol like gasoline, or for that matter water, presents no special problems from a pipe-line standpoint.

It has been suggested that pipe lines might be built to handle other commodities; certainly for quite short distances grain and coal may be moved in this fashion by compressed air. The cost of compressed air and the probability that any dry commodity would be reduced to a powder in an extended journey through a pipe, together with the difficulties experienced by the natural gas industry in keeping its pipe lines clean, lends small encouragement to prospects of this form of transportation.

Hydrogenation of coal probably offers a better prospect as the resultant liquid could, of course, be piped like any other fluid. It is also possible that coal may be reduced to a gaseous mixture and piped while in this state. Considering, however, the low value of coal, the remarkable efficiency with which it is transported by railroads, waterways, and even on short hauls by motortrucks, considering also the growth of natural-gas pipe lines, and particularly surveying the transmission of electric energy, it seems unlikely that piping of hydrogenated coal will be an important item in the next two decades of transportation.

If an abandoned pipe line could be acquired at scrap value, and were advantageously located to serve both a coal field and a coal market, it is conceivable such a venture might be commercially practical.

In the main, however, the petroleum and gasoline pipe lines are plant facilities of the oil companies, and their development in the next 20 years will depend upon the development of the petroleum industry it-

self. Within their own relatively narrow field of transportation, pipe lines have a virtual monopoly of the crude oil business and will obtain an increasing share of the gasoline traffic. Their seemingly impregnable competitive position, however, arises from their ability to render a specialized transportation service more cheaply and efficiently than any other agency.

It should be noted that pipe lines really do not deal as common carriers with the general public; the benefits of this kind of transportation accrue to the producers and refiners and only indirectly to the common man.

Air Transportation

Transport Operations

In the year 1926, 5,800 passengers were carried in the course of regularly scheduled air transport operations in the United States: our airlines are now handling over 100,000 passengers per month. How far the 5,800 hardy pioneers traveled is unknown; the average journey today is in excess of 400 miles. In 1937 the passenger miles flown on transport planes will probably exceed half a billion.

In 1926, 800,000 pounds of mail were carried, and in 1935 over 13,000,000 pounds.

Figures like these, marking the rapid development of civil aeronautics in the United States, can be compiled to wearisome statistical lengths. The amazing growth of aviation, the novel and spectacular nature of the industry, and the realization of man's age-old dream of flight have combined to put flying first in the public mind whenever transportation is discussed.

Probably popular imagination as to this form of transportation is somewhat overstimulated. Passenger-miles flown in the Continental United States in 1933 were 173 million, as against 16 billion passenger-miles handled by the railways and 185 billion by private automobile in intercity travel. While it is true that the transport plane passenger-miles almost doubled between 1933 and 1935, and will quite probably double again before 1940, we are still talking about a transportation agency handling only a fraction of 1 percent of the business.

We are also discussing a form of transportation that, while in many ways only on the threshold of its development, already faces definite fundamental limitations.

Short-haul traffic as between New York and Philadelphia is, of course, out of the question—from the standpoint of time alone the plane is inferior to the train. On longer hauls, as between New York and Washington, air travel may save an hour out of 3½ hours, but for most people this is not enough to justify the safety factor and particularly the higher fare. Where airports can be relocated closer to large cities, air transport will profit correspondingly.

In addition to regularly scheduled transport operations,[4a] which in 1935 involved about 350 planes in do-

[4a] An airway map of the United States showing scheduled transport operations is available from the Department of Commerce, Division of Aeronautics.

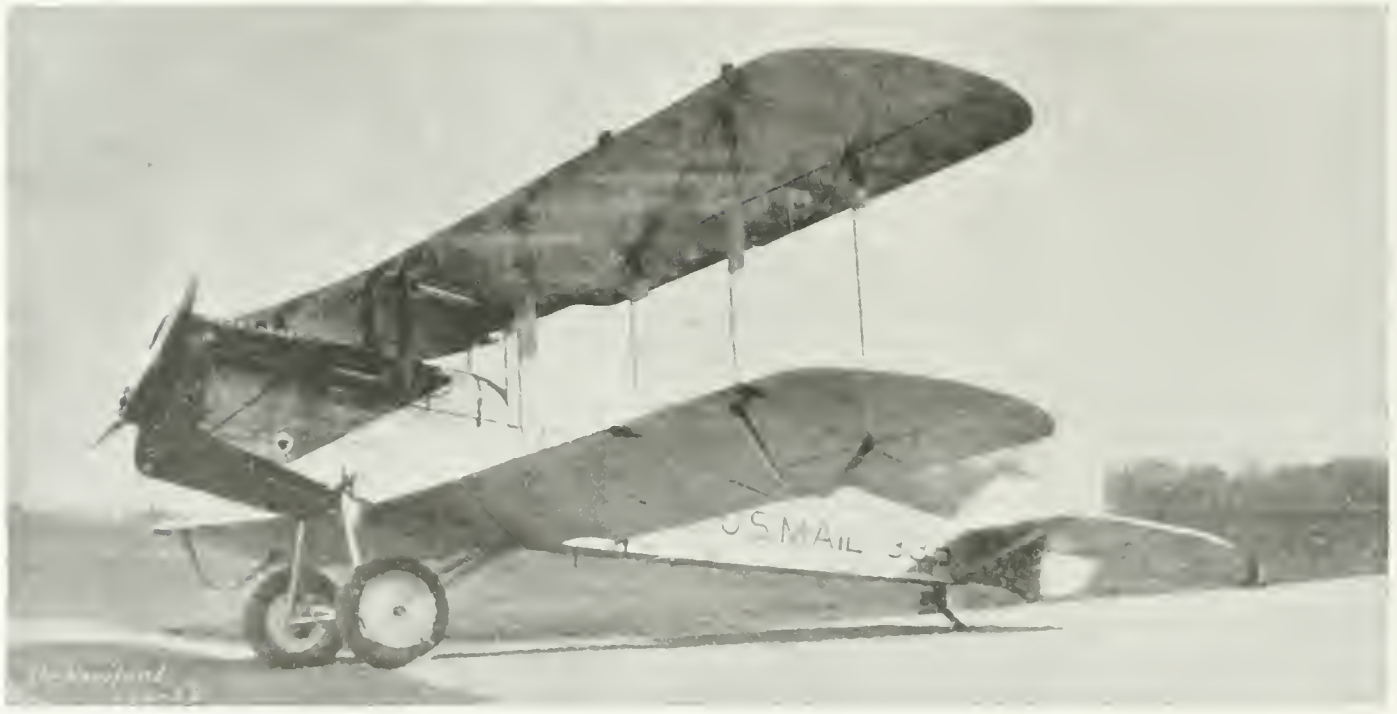

FIGURE 38. De Havilland mail plane used for transportation of mail in the early 1920's.

mestic service and 100 in foreign, we had about 8,500 licensed and unlicensed other airplanes in operation carrying a million passengers. A great many of these people merely made 10-minute sightseeing flights at airports on pleasant week-ends, but the figures also include strictly transportation flying.

Quite a number of companies and individuals own airplanes, and some flying is done in specially chartered planes, although the average rate for the latter sort of service is about 20 cents a mile. Charter operators carry passengers on flights which are not made on scheduled airlines—for example, from a city which does not have an airline to one which does, or at some particular hour.

Unless one has closely followed the amazingly rapid developments of aviation and generally unless he has actually flown, it is highly improbable that the average man realizes the present stage of civil aeronautics in the United States.

Air liners going into service in June 1936 are 21 passenger bimotored low-wing monoplanes with top speed of 215 miles an hour.

Air lines are now asking for a plane capable of flying 900 miles nonstop with 40 passengers, or 2,000 miles nonstop with 20 passengers and berths. Such a plane is to use four engines, each developing 1,000 horsepower at sea level and 900 horsepower at 9,000 feet altitude. A top speed of 230 miles an hour is asked, cruising speed of 210 miles an hour at 75 percent engine rating, and 193 miles an hour at 60 percent horsepower.

That present passenger planes rival any form of transportation in comfort and even luxury, and far surpass other agencies in speed, is generally accepted by the traveling public.

Unlike railroads, which have to own and maintain their lines and terminals, the transport airplane to a large degree depends upon Federal aids to air navigation and, of course, on the aid of cities for terminals. At the end of 1935 our principal airports were owned as follows:

Commercial and private	552
Municipal	739
Intermediate—Department of Commerce:	
Lighted	282
Unlighted	9
	1,582

The Department of Commerce lighted over 22,000 miles of airways, operated 74 radio broadcast stations, and 137 radio range beacon stations, and had over 13,000 miles of teletypewriter service principally for handling weather information.

Courtesy American Airlines, Inc.

FIGURE 39. Douglas transport.

As to the future the aircraft manufacturers and operators, who in the past have experienced extreme difficulty in looking ahead as much as 3 years, are naturally hesitant.

To date the factor of obsolescence has been disproportionately large from a commercial standpoint: ships have been changed about every 3 years in response to increasing demands for higher speeds, better accommodations, and larger carrying capacity. From this standpoint too rapid a development of planes would probably be unfortunate—no transportation agency can long stand a 2½ percent per month depreciation on its fixed capital.

It should be borne in mind that from the standpoint of physical depreciation alone the modern transport plane probably has a life of 8 or 10 years, subject to ordinary maintenance and the replacement of its engines generally after every 3,000 or 4,000 hours of flying. The accompanying photographs of the exteriors and interiors of planes of 10 years ago and of today show vividly the obsolescence which has made the actual physical life of a plane unimportant up to now.

Technical development of the planes themselves is slowing down; streamlining is pretty well worked out; comfort has reached the stage where it is second only to speed as an attraction; the ships are tending to standardize particularly as to sizes; increased safety depends more on radio beacons and communication and well-planned and lighted landing fields than on improvements in materials or designs of the planes themselves; and from a strictly commercial standpoint the airlines will be in a better position as this slowing-down process goes on.

In the words of one of the leading aircraft manufacturers:

> Efforts will always be made to increase speed, consistent with other factors, but the trend at the moment seems more toward safety and comfort than to the greatly increased speeds. Present speeds permit of quite fast schedules and in my opinion, the only pressing need for speed now is to give the airlines the larger margin to maintain their present schedules rather than to allow them to better their present schedules.

One technical development, however, will be the construction of a limited number of planes to fly at altitudes above 20,000 feet. At such heights cruising speeds around 240 miles an hour may be obtained without proportionate increases in operating costs—roughly each thousand feet of elevation permits 1 per-

FIGURE 40. Interior of one of early passenger airliners (Ford).

cent increase in speed. At such levels, also, air conditions for smooth flying—regardless of disturbances below—will be advantageous.

From the standpoint of motors, controls, and flying technique, such operation will involve no unusual problems—most of the necessary work along these lines has been done by the military and naval establishments of the world. Much work, however, remains to be done to provide comfort and safety at these levels for the passengers who even today are sometimes unpleasantly affected by the rarefied atmosphere reached around 9,000 or 10,000 feet above sea level. This involves the design of a cabin in which the air is held at a comfortable pressure—not necessarily sea-level pressure, but materially more than prevails at the altitudes where a plane will fly.

Air pressures in pounds per square inch are as follows:

Altitude (in feet):	*Pounds per square inch*
Sea level	14.7
5,000	12.3
10,000	10.3
15,000	8.6
20,000	7.3
25,000	6.0

A difference between interior and exterior pressures of only 3 pounds per square inch would mean half a ton total pressure on a window 18 inches square. Translating such figures into the terms of a cabin 100 feet long, the problems of preventing distortion of the structure, leakage of the air, and at the same time holding weights within allowable limits are apparent.

If we had such planes today they probably could only be used advantageously on a limited number of nonstop routes—New York to the Coast and to Miami in the season, Chicago to the Coast, and possibly between Chicago and New York. Limiting factors are traffic density and the time and distance it will take such planes to climb to high levels and descend from them. Obviously to derive any real advantage from flights in the substratosphere planes must remain at high altitudes for an appreciable time and distance which is impossible except on such flights as suggested above.

Extension of airline service will be made as traffic develops. The principal air routes are already established but some supplemental or feeder lines will be developed from time to time. From the public standpoint the most spectacular features in sight will be the extension of the Pan American Airways for passenger service, not only to Manila where mail and express

FIGURE 41. Interior of Douglas DST with seats, arranged for day flights. At night these seats become berths.

are already carried but (barring international difficulties) to China, and the probable inauguration of a similar service across the Atlantic.

Representatives of the United Kingdom, the Irish Free State, and Canada, have already reached understandings with the United States under which trans-Atlantic scheduled airline service may be established by way of Canada, Newfoundland, and the Irish Free State to England by way of Bermuda to England, and also from Bermuda to Puerto Rico (which, of course, is now reached from Miami via Cuba).

The Department of Commerce is authority for the statement that experimental flights are planned for this spring, and trans-Atlantic service will probably be on a regularly established basis not long thereafter.

Safety

Judging by the number of plane miles flown per fatal accident, the 1936 safety record, including the disasters in December, was better than 1935. Judged by the number of passenger miles carried per passenger fatality, the record was worse. Despite the fact that only one passenger was killed per 25,000,000 passenger-miles flown in scheduled air transport operations in 1933, and one fatality in 21,000,000 miles in 1935, the question of safety is still probably the greatest single deterrent to air travel.

Broadly speaking, the transport plane experiences few mechanical failures and, except for unusual ice conditions, is virtually independent of weather hazards once it is in flight. The difficulties lie in navigation, in weather conditions at the terminals, and in the terminals themselves. Navigation is being constantly improved through world-wide study of the weather, through more and better aids particularly in the field of radio and in further education of an extremely efficient personnel. Weather conditions at terminals cannot be changed, but will doubtless be more quickly and accurately forecast—the increasing speed of planes gives less margin for error. Improvement in location, design, and lighting of airports themselves is progressing rapidly and will be one of the most important things making for increased safety. Adequate supplies of gasoline aboard planes have contributed greatly to the safety of operation, a large supply of gasoline permitting a wider choice of airports under adverse weather conditions.

Air navigation in the future in this country will probably depend more and more on radio beacons, both the beams and the low-powered markers, and much more extensive meteorological studies. Constant improvements in radio communication will be an important factor. For relatively short distances and particularly for individual flying the lighted airways will remain of service, but in transport operations the pilot will increasingly be the counterpart of a ship's navigator rather than a locomotive engineer taking his train from one block signal to another.

The air lines have been working on radio compasses for several years and at least one company will equip all its planes with these devices early in 1937. Probably to supplement the radio beam and the radio compass, ground stations will be equipped with radio direction finders so that they can plot the position of a plane and send it to the pilot. This is, of course, precisely the service ocean vessels receive from land stations such as Nantucket, Atlantic City, Norfolk, etc., which by taking cross-bearings can accurately plot the steamer's position. One air transport line has been doing experimental work of this nature for a number of years.

Private Flying

Private flying—owing to the cost of planes, the time and expense needed to train operators, and the abundance of other cheap and rapid personal and common carrier transportation—will follow the early history of the automobile business at a respectful distance. Our early motorcars were the playthings of wealthy sportsmen and professional race drivers. People with an adventurous disposition backed by sufficient funds will use planes for recreational flying and particularly to reach inaccessible hunting and fishing country, summer residences, etc. Oil companies, electric power producers and other businesses whose operation is spread over wide areas will gradually make greater use of private planes.

Development of private flying beyond these types will have to be on the basis of lower cost planes with greater simplicity of operation and safety in the hands of less highly trained personnel than transport pilots. Experimental work is being done along these lines and the accompanying photograph gives a good idea of one of the more recent developments.

Another type of plane peculiarly adapted for private flying is the autogiro, which is just emerging from the experimental and primary development stages. The autogiro, through its ability to ascend and descend at extremely sharp angles of flight and requiring, therefore, only limited terminal facilities, can reach places otherwise inaccessible to air transport. In speed, power, comfort, economy of operation and cost, however, the autogiro has no advantages over ordinary airplanes and will, therefore, probably have a less rapid development.

Lighter Than Air Craft

Use of lighter than air craft of the Zeppelin type within the continental limits of the United States is out of the question. The Hindenburg has no advan-

FIGURE 42. Hammond monoplane.

tage in speed over railroad trains; is more dependent on weather conditions than transport planes, and from neither technical nor commercial standpoints is adaptable to the type of service rendered by airplanes. On trans-oceanic flights, however, such ships have already set high standards for comfort and safety. Even if equal safety be granted—and this of course remains to be proved in the North Atlantic service—the comfort of ships like the Hindenburg combined with its economy of operation should largely offset the superior speed of transport planes. Moreover, these lighter-than-air craft have a real freight-carrying capacity admirably suited to the transportation of luxury goods. Like the transport plane, material failures are relatively few and, in expert opinion, the success the Germans have had with their Zeppelins is largely due to profound studies of meteorology and air navigation as an art in itself by an extraordinarily well-trained personnel.

Future Developments in General

While commercial air transportation, on account of the limits of time and space, is primarily adapted to much longer distances than the average passenger journey, it is still capable of large expansion. Bigger planes and more of them will improve the numerical relationship of air-line employees to passengers carried and cut operating costs per passenger mile. Long-distance first-class mail will be handled in much greater volume, if, as has often been suggested, we have a single first-class postage rate and the mail dispatchers are free to send each letter by whatever method is fastest.

The growth of air express traffic, at present in its infancy, will greatly increase transportation of perishable commodities, such as fruits, flowers, and sea food, and all first-class freight and express, characterized by high values and low weights per cubic foot, will be handled. Older passenger planes can readily be converted to this service and thus have a better chance of lasting out their physical life in service comparatively free from obsolescence.

These considerations all point to lower airplane fares and the reduction from an average per-mile rate of 12 cents in 1926 to 5.7 cents in 1935 will continue to levels probably not much out of line with those of our extra-fare all-Pullman trains.

As transport flights to some degree represent business lost by railroads, so private flying will largely be at the expense of the private automobile.

In the entire field of passenger transportation, however, definite limits are not yet in sight and these shifts from one form of transportation to another will be less important than the new business created and developed by cheaper, more comfortable, safer and speedier transportation agencies.

The social implications of air transport of the future differ in degree rather than in kind from what we have today. High-speed trains and automobiles have long ago rendered county and state lines meaningless, have widened trade territories, and brought once distant regions close together. Air transport does not change, but intensifies these effects.

The effect of aviation on employment will be beneficial. The construction, operation and maintenance of aircraft, their high obsolescence and comparatively short physical life, are favorable employment factors by any railroad standards. More important is the fact that passenger traffic, unlike freight, can be created. The probability is that far more traffic will be created by aviation than is diverted from other transportation agencies.

Urban Transportation

City transportation of passengers, at one time almost altogether handled by electric street railways, has more and more drifted to the motorbus and the private automobile. A few large cities, notably Boston, Chicago, New York, and Philadelphia, have extensive suburban passenger services operated by steam railroads (in some cases with steam locomotives, in others by electric power). Most cities, however, depend principally on trolley cars and motor vehicles.

Facing generally unregulated and destructive competition over most of the past 20 years, the electric street railways have lost about a third of their traffic. Fifteen and one-half billion passengers were carried in the peak year of 1923, and about 10.3 billion in 1935. Like the steam railroads, the street railways are battling to hold what traffic they have left and to regain some of the business they formerly enjoyed.

Like the steam railroads, too, the streetcars now have to meet the demands of a public which requires a good deal more than the bare necessities of transportation. Comfortable lighting, frequency and regularity of schedules, quietness of operation, and greater speed, are being asked of all passenger transportation agencies and the streetcar is in no way an exception.

The future of urban transportation seems unusually obscure. Probably this is because the trends of all urban development—particularly in the larger metropolitan areas—are uncertain.

The National Resources Committee in their "Studies of Urbanism" are making an exhaustive analysis of mass transit facilities and their effects on the internal development of urban communities and regions. They are considering not only the different forms of urban transportation, the effects which the internal organization of urban communities have on the use of city transit, but also the possible modifications in transit and traffic practices and policies advisable in furthering healthy urban and regional growth. This work when completed should shed a good deal of light on a decidedly dark subject.

Today, however, a typical forecast of the future of the electric street railway is that of the Federal Power Commission in its recent survey of the use of electric power in transportation. The Commission says:

> It is dangerous to prophesy, with conditions changing so rapidly, just what effect these developments will have on the electric railway industry. There should be a rebound in its business from the depression lows, with an increase in power consumption, but whether or not the trend will continue upward or begin another decline is unpredictable.

Perhaps, however, a rather surprising lack of competition in this particular field of prophecy should encourage rather than deter a student of transportation. It may still be possible to venture somewhat cautiously where "angels fear to tread."

Elevated Railways

These are definitely on their way out. Their noise and unsightliness, the inconvenience of climbing to their stations, their devastating effects on property values make any extension of this form of transportation highly improbable.

Some of these roads have already been torn down, and it is probable that we shall have a gradual elimination of others.

Subways—Rapid Transit Systems

The construction of subways depends on concentration and density of population—that is to say, the geography of each individual city. Manhattan, a long, relatively narrow island, where millions of people must be transported in and out of a comparatively small area daily, could not function without subways. Cities where the population is spread over wide areas, as in Detroit or St. Louis, present a totally different problem, making subway construction unlikely.

Like electrification of a steam railroad, it is almost entirely a question of traffic density; and few of our cities, regardless of how large their total population, have enough potential traffic concentrated along any one line to warrant the cost of subway construction.

Subways—Street Railway

Based on Boston's 40-year experience of routing surface streetcars through a comparatively short subway loop, the suggestion is frequently made that this scheme might be a solution for the traffic problems of many cities where real rapid transit subways, like New York has, are out of the question.

Here, however, is an expensive form of construction which is not high-speed transportation. The Boston streetcars were forced underground by sheer congestion of relatively narrow streets, but the local geography of Boston is admittedly unique. Were some similar plan applied to the ordinary city, the benefits to the individual passenger would probably be relatively unimportant. Instead of stopping at every corner, stations could hardly be spaced more

closely than every three or four blocks, necessitating correspondingly longer walks for the individual. Climbing and descending stairs, passing through turnstiles, hunting up a particular spot on a long platform in order to take a car for the desired route, and similar minor delays, would all consume a good deal of the individual passenger's time. Against this, any increased speed would be but a minor offset owing to the relatively short lengths usually discussed for such subways.

Trolley Bus

This type of transportation consists of a bus using two overhead wires for an electric circuit, but running on the street like any other vehicle—"a trackless trolley." Considering the aesthetic objections to overhead trolley wires and the long effort of most cities to get all wires underground, this type of transportation will probably not be received with general enthusiasm.

Where streetcar tracks have been pulled up and the overhead wiring remains, operation of trolley busses may serve as an intermediate phase of transportation. That most cities, however, would widen a street, permit streetcar tracks to be taken up, and still keep overhead wires, to which, of course, practical objections (in case of fire for instance) as well as aesthetic, may be registered seems improbable. Even less probably would a city permit overhead wires to be strung where none now exist.

Trolley Lines

Like the steam railroad, the electric street railway has been peculiarly vulnerable to automotive competition in regions and on lines of light traffic. Twenty-six thousand miles of city and suburban street railway tracks were operated in 1922 and about 20,000 in 1932—a decline of 22 percent. Meantime the operation of 38 percent of interurban track miles was abandoned. The street railway has proven incapable of shifting its lines to meet shifts in business and population within our metropolitan areas. Where a reasonable density of traffic is available, the trolley car has been more successful, and this is particularly true where new and improved types of cars have been put into service.

Strongly influenced by automotive design, the new cars, such as now used in Washington, D. C., for example, provide much more smooth and rapid acceleration and deceleration. Noise and vibration have quite largely been eliminated; seating is more comfortable, illumination, heating, and ventilation improved, weight less, and great improvements have been made in the highly important feature of appearance, both exterior and interior.

The street railway, however, on the whole seems to be a good example of the type of things which can go ahead for a while because they are already here, but which would not be built under today's conditions. Logically it should follow, and actually it has followed, that when the street railway is confronted by the necessity of major changes, such as complete reconstruction or relocation of tracks, the more economical policy is to discontinue operations and substitute automotive transportation. For this reason it seems as though on the whole, in most cities, the busses will rather gradually gain on the street railways.

Busses

Because it does not have to provide its own right-of-way, the bus is well adapted to operate with the utmost economy in light-traffic areas. Busses also can be economically built in a wider range of sizes than streetcars, providing a desirable flexibility of services; the small bus to some degree makes up in speed and frequency of service what it loses in passenger capacity. Mention has also been made of the fact that busses can readily shift their routes with the development of particular sections of the community or the stagnation of others. In periods of temporary traffic interruption occasioned by accidents, fires, broken water mains, and other hazards of metropolitan life, busses may readily be detoured. From the standpoint of the individual passenger, bus stops at the curb are far more convenient than streetcar stops in the middle of wide boulevards full of rapidly driven automobiles. Not only from the disabilities of the street railway but from these definite superiorities of busses, the latter should gradually gain on the "trolleys."

Private Automobiles

To how great an extent the private automobile figures in urban transportation has never been determined statistically. That it is the dominating factor outside of travel to and from central business districts is plain. To what extent it is used to go downtown and back is largely a question of the local geography of individual cities. An extremely small portion of people working on lower Manhattan Island use private automobiles to or from their offices and, obviously, a large portion of the population of places like Indianapolis and Kansas City drive their own cars to and from work.

Where a reasonably speedy and frequent bus or streetcar service is available, the average automobile owner seems entirely willing to use it. To obviate the difficulties and delays of driving and particularly of parking, to save money in the process and to gain safety and comfort, especially in extremely hot, wet, or cold weather, are worth a good deal to the ordinary businessman or shopper.

General Considerations

The most important single factor in urban transportation in the average community is the use of its downtown streets. If they exist largely as storage facilities for parked automobiles, neither bus nor streetcar can supply truly rapid and convenient transportation. If, on the other hand, the downtown streets are generally cleared of all but moving vehicles, the problem of urban mass transportation is well on its way to solution. Certainly any consideration of the greatest good for the greatest number points toward elimination of downtown parking, which would lead to provision for parking facilities on the outskirts of congested districts. Failing substantial progress along these lines, it is by no means inconceivable that private automobiles may be denied access to certain areas, at least at certain times of day. It seems unlikely that people who ride 40 or 50 in a bus, or 75 to 100 in a streetcar, will permanently suffer the delays and inconveniences occasioned by private motorcars occupying equivalent spaces in the streets.

Future Social Implications of Transportation

For two reasons little has been said about the future social implications of transportation.

In the first place we have a great and highly efficient transportation system today, the social effects of which are plain to all of us. This system is constantly being improved in speed, comfort, flexibility, and in lowered cost, but this progress is in degree rather than in kind. We are improving a wonderful machine. We are readjusting the machine to handle a freight traffic consisting more largely of consumer goods and relatively less of capital goods than in the past, and to serve the rapidly increasing passenger traffic of a surprisingly nomadic society. We are not, however, discarding transportation service in favor of something else as, theoretically at least, our current models of contented cows may be rendered obsolete by synthetic milk from a chemical plant.

In the second place the volume and character of transportation, both freight and passenger, depend largely on factors, social and otherwise, quite outside of the transportation industry. This thesis depends on no narrow interpretation such as making the rather obvious point that transportation is completely dependent upon power. Rather let us realize that the exhaustion of mineral resources, or the destruction of timber in a region may leave no freight traffic in that area. A failure of the California citrus fruit crop, a drought in the Kansas wheat belt, a strike closing the Illinois coal mines, the completion of a great new hydroelectric power plant in Tennessee—all such things have a profound temporary and frequently a permanent effect upon the transportation industry which itself cannot take any counteraction. Similarly, shorter hours, higher wages, greater old-age security, and better education will favor increased passenger travel just as the long hours and poverty attendant upon farming submarginal land virtually root people to the soil.

Within the transportation industry itself the social prospects for the future are good. The internal shifts will probably be toward types of service employing relatively more operating personnel per traffic unit than the business of the past has required.

Probably three-quarters of our million railway employees are engaged in a freight service handling 236 billion ton-miles annually: motortrucks, according to the Automobile Manufacturers' Association, employ 2½ million drivers alone to handle 10 or 15 percent as much business. This indicates that motortrucks furnish 20 or 30 times as much employment per ton-mile as do railroads. While the figures are not completely accurate (as previously pointed out) nor the statement of the case entirely fair owing to the somewhat different nature of the traffic, so wide a difference may be liberally discounted without impairing the validity of what it implies.

Similarly, air traffic, which will increase at a higher rate than other forms of transportation, is a liberal employer of high-class personnel.

Changes in freight transportation do not ordinarily affect us directly. Most people have never even seen a pipe line; millions have never heard the whistle of a big ore carrier or a tank steamer. A long freight train may occasionally block us at a grade crossing, or a big truck get in our way on the road. In passenger transportation the contact with our daily life is a good deal more direct. If we live near water we may take a steamer occasionally; more frequently we ride on trains; less frequently we may fly.

One transportation agency, however, is part and parcel of our daily life—the highway and the motor vehicles that use it. It is unnecessary to attempt to catalog the obvious influences of motor transportation ranging from its evil effects upon the hammock business through the many conveniences, the different kinds of usefulness, the broadening recreational opportunities, the recasting of the pattern of farm life, and so on to the vision (or nightmare) of half our population living in trailers. Even the slightest reflection as to how elimination of all motor vehicles would affect us would produce a picture quite as appalling as those drawn of a world without electric power. That the world managed to get along without the "high line" and the motorcar until quite recently (in 1895 four automobiles were registered in the United States) is perhaps beside the point. From the fact that the

ordinary automobile owner will surrender almost any of his possessions and make material sacrifices in his way of living, if only he can hang on to his car, we may infer how largely highway transportation bulks directly in our lives.

In at least one semidirect fashion, however, all better and cheaper transportation comes into contact with us—a standardization of life all over the United States. It is probably unfortunate that people are more frequently irritated by alleged likeness to other folks rather than by differences, for the trend is undoubtedly toward uniformity. A Virginian would probably resent the statement that life in Charlottesville differs but little in its essentials from life in Columbia, Mo., or Princeton, N. J., but the similarities in tangible things certainly far outweigh the differences. In bringing about this standardization, transportation is not, of course, the only influence, but it is plainly the service which alone makes it possible for the underlying and unifying influence of commerce to function.

While not merely volumes but libraries might be written as to the part transportation plays in our civilization, the essential facts are too well known to demand inclusion in a paper of this scope.

Two quite modern and still rapidly developing influences should, however, be noted. First is the improved quality of freight and passenger service, particularly in speed and reliability. The producer, the manufacturer, the merchant, the public utility, or the individual is getting a freight service measured in hours instead of days, and in days instead of weeks, even as compared with 15 or 20 years ago. With this increased speed has come greatly increased reliability, and the influences of both have been profound.

Inventories need only be sufficient for a few weeks, where months were formerly necessary; goods are in transit a few days instead of a matter of weeks; a tremendous amount of capital formerly locked up in these items is now released. Investment of capital in storage facilities may be diminished; the cumulative processes of converting raw materials into finished goods are steadily being speeded up. Carrying less stock, stores become decreasingly vulnerable to changes in styles and to whims of public fancy; with less money tied up in their inventories, manufacturers are more ready to modify their products to suit changing demands.

Improved service affects the transportation industry itself by requiring less equipment.

Granting that speed means less to a distillery aging its products for several years than to an automobile manufacturer who proverbially wants something delivered yesterday that will not be ordered until tomorrow, the effects of better transportation are almost universally felt and of increasing importance This trend will continue.

Increased speeds in passenger transportation permit much broader and more intensive solicitation and servicing in a business way, and a greatly increased range of recreational and semirecreational travel.

The second great development in transportation in recent years has been the increasing ability of the individual to supply his own freight and passenger service, and to some degree render himself independent of common carriers.

The overwhelming bulk of passenger transportation is already an individual matter—the private automobile dominates the field both in business and pleasure travel.

In freight traffic the petroleum pipe lines have a common-carrier status but in the main transport the oil of the companies which own them, or with which they have a community of interest. Even the outside shippers are generally large and represent other units of at least partially integrated oil groups. Oil companies also own and operate large numbers of tank steamers.

Probably about 85 percent of the motortrucks are privately owned and operated, and the total volume of freight handled by trucks is increasing more rapidly than the business handled by railroads or waterways.

This growth of privately owned freight and passenger transportation agencies is chiefly important for its influence on rates. Passenger rates of common carriers cannot stray too far from what motorists think their travel costs them—unsound as it is for a car owner to keep a record of his gasoline purchases and ignore the far more important items of ownership costs such as personal property taxes, insurance to cover half a dozen contingencies, and above all depreciation.

The present freight rate structure will be materially modified through the trucks' influences on pickup and delivery service, packing requirements, more liberal classification of freight, and the level of the charges themselves being based, to an increasing degree, on cost of service. Ordinarily lower freight rates widen trade territories and intensify competition rather than increase the volume of business. More ton-miles may be produced, but with a narrower margin of profit.

The Interstate Commerce Commission must have in its records thousands of pages of testimony and exhibits tending to prove how small are the freight charges on a necktie from Paterson, N. J. to Syracuse, N. Y., and a pound of flour from Franklin, Tenn., to Louisville, Ky. Quite dissimilar testimony pictures the alleged crushing burden laid upon commerce by rates on gravel or coal.

Whether or not lower freight rates mean much on any specific commodity is immaterial; transportation

costs in the aggregate are a large element in the costs of our material civilization. Anything reducing this element, provided it allows a fair living to the transportation agencies themselves, is plainly beneficial.

We have a transportation system made up of widely diverse agencies. Some of them are closely related and furnish comparable competitive service—for instance, railroad and highway transportation. Others in the nature of things can be neither competitive nor cooperative—the transport plane and the pipe line are the best examples.

Mississippi River vessels compete with railroads on freight, but not on passenger business. The pipe line has virtually driven the railroad out of hauling crude petroleum, but today offers no competition on other commodities save gasoline. The bulk of freight transportation is performed by common carriers. The privately owned motorcar dominates the passenger field.

While the average man will not be inclined to quarrel with the statement that each form of transportation has its peculiar advantages and that all should be used in a way to permit the greatest utility for each, the practical difficulties in achieving this desirable end are plain.

Are we to say to the truck owner that he may not haul freight between Chicago and the Missouri River because the railroad is a more economical means of transportation? Shall we, as a matter of public policy, deliberately seek to force traffic to one transportation agency because it is necessary to our system of national defense or for other reasons? Shall we turn over the mail, so far as possible, to the air lines and fix their passenger rates in some definite relationship to railroad fares?

Probably we may arbitrarily do a great many things of this sort as temporary or experimental measures even in peace times and more certainly under the stress of war. The difficulties of doing anything of the kind under normal conditions, however, are obvious. Even were all our forms of transportation owned and operated by one agency instead of by hundreds of companies and literally millions of private individuals, the problems involved are entirely too large and far reaching to encourage one's sense of omniscience. Nor are the problems of transportation static—the movement of freight and passengers is in a constant state of flux, shifting with changes in agriculture, industry, trends of population, and all the multifarious factors of our modern civilization.

The difficulties and the magnitude of transportation problems do not preclude the possibility of beneficial and effective coordination and regulation. They are worthy of careful scientific and sympathetic study by the ablest men we have.

It seems clear, however, that whatever regulations we have should be uniform. If we fix rates for one transportation agency, its competitors should not be free to make their own rates. If it is necessary to establish hours of service for the driver of a common carrier motortruck, it is equally necessary in the case of a privately owned truck.

Probably regulation of transportation in the future will be needed more for coordination and the prevention of unfair competition than to bring about reductions in rates.

That some measure of regulation will be applied, even to private, as well as public carriers, seems inevitable.

In the past 15 years we have seen an almost incredible increase in passenger transportation, due to the convenience and low cost of private automobiles. Recently reductions in long-distance telephone rates in Great Britain have greatly increased the gross receipts of the British Post Office, which operates the telephone lines in that country. Today, lightweight, high-speed, streamlined trains and low passenger fares are increasing railroad travel. It is notable that transportation, as it becomes more speedy, regular, frequent, economic, or efficient, creates, like other public services or utilities, an increased demand.

The history of transportation has shown that as a whole it grows at a rate higher than the increase in population. Our transportation service will hold its world leadership; it will continue to develop and adapt itself to the changes in the American scene, and it will become increasingly adequate and responsive to whatever demands are placed upon it.

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IV. COMMUNICATIONS

By T. A. M. Craven and Committee and A. E. Giegengack[1]

Introduction

Communications in its broadest sense embraces all forms of the transmission of intelligence from one person to another.

From the beginning of mankind, human endeavor has been centered upon the communication of intelligence between persons not in direct contact, and this basic urge of mankind resulted first in a method of transmitting thoughts from one place to another by means of a courier intermediary. Since this intermediary depended upon memory, and since he was relatively inefficient, his memory was replaced by the writing of signs onto a permanent record which in turn was carried and delivered by the courier. Thus with the earliest beginning, it is possible to trace the two main branches of communications, namely, (1) The methods involved in the transmission of recorded messages, and (2) the methods involved in the transmission or relay of voice.

A section dealing with printing and photography, both of which play a very important part in communications, is presented by A. E. Giegengack in the second part of this chapter under the heading "Printing and Photography."

The most important communication developments of modern times are the telephone, telegraph, and radio. Important adjuncts to these developments are the vacuum tube, facsimile, television, devices which permit multiplex communication over single carriers, and modern methods of printing and photography.

Naturally, in any communications system which is to be used by all people, the most important consideration is the availability and organization of communication facilities at any one particular place or area, and in this phase of communications, it can readily be recognized that the modern-day organization and availability of communication facilities is the important factor which has the greatest effect upon the social and economic welfare of the peoples of the world.

Today the necessity for rapid, efficient, and cheap communications has been thoroughly recognized as a well-established benefit to mankind. Modern communications, while still inadequate in various parts of the world, are a most important adjunct in the economic life of nations and individuals, and they have borne and will continue to bear a most important influence upon the social and economic welfare of the entire world. A single illustration will serve to demonstrate this fact when one considers a comparison between the difficulties of government in the United States during the early days of the Republic and the present day. If the 130,000,000 people in the United States today utilized the methods of communication of 1776, no one can state that our present form of government, our economic structure, and our social habits would be as we know them today. Looking into the future, with the advent of radiobroadcasting, one can visualize further improvements and benefits in the art of self-government, because even though broadcasting is today only 15 years old, its effect upon the life of the country has been most marked because of its inherent ability to provide for instantaneous mass communication over tremendous distances, thus welding the people of the country into a unit unparalleled in history.

When one adds to aural broadcasting the ability to see and to record permanently what one has seen and heard, there will have been attained a perfection in communications which will certainly have the most profound effect upon our social and economic life.

Broadly speaking, the most important technological developments which will enhance the effect of communications upon the future public life are those which will increase the speed and availability of inexpensive communications. These are now in the process of development, in the form of facsimile, television, and methods to increase availability of channels. The first enables the instantaneous transmission of permanent records, photographs, the printed page, and other signs; the second permits the transmission and reception of objects, and the third increases the number of voice and record channels and cheapens the cost of communications.

Of course, there are hundreds of individual inventions which will tend to improve the details of facsimile, television, and multiplex operation, but the principal developments are those which now make it possible to apply to public service facsimile or television either through the use of land line or through the use of radio, either for person to person contact accompanied by voice, or for mass communication. Probably the most important developments in the ap-

[1] The section of this chapter dealing with Communication by Wire and Wireless was prepared by a committee of the Engineering Department, Federal Communications Commission, of which T. A. M. Craven is Chief Engineer. Other members of the committee are E. K. Jett, A. D. Ring, John J. Hassler, and Gerald C. Cross. A. E. Giegengack, Public Printer, submitted the section on Printing and Photography.

plication of these broad systems of communications will be the organization of facilities to make their use by the public possible and more easily available. In radio there will be necessary many inventions to increase availability of television and facsimile to the public, since at the present time there is an inherent natural limitation in the use of the radio spectrum which has yet to be conquered by man's ingenuity.

There will be required in the future a balance between the unlimited possibilities of facsimile and television as against the limitations imposed by natural, economic, and social circumstances. Nevertheless, one can safely state that ability to have one's newspaper printed in the home, ability to see and hear news in the making, ability to transmit quickly from one point to another a written document, and the ability to see and hear the person with whom one desires to communicate, even though he may be separated by thousands of miles, must have a marked effect upon the daily life of anyone living in this modern age. That this may affect the social habits and daily routine of an individual family or that it will affect the economic welfare of the Nation as a whole, cannot be overlooked.

Adjustments will have to be made to accommodate the rapid changes in the panorama of the future as compared with that of today. With the ability to see and hear from persons at a distance when one is traveling by airplane, automobile, or steamship, as well as when one remains at home, or as one conducts business in an office or works in a factory, it appears inevitable that the mental processes of the future must be such as to produce an entirely different outlook than exists under circumstances when one's vision, horizon, and social contact are limited.

It also may be expected that these new developments will speed up ordinary life and business, and will affect certain existing industries, such as the motion picture, the newspaper, advertising, and the existing telegraph, telephone, and radio systems of the country. The effect of these developments upon the industry and their consequent effect upon commercial activities in every walk of business life, requires modifications of economic views which exist today.

In education, the application of these modern methods of communication may well effect a complete change in methods of educating not only the child and the adult but also the entire public. The new communication development may also revolutionize the present school systems of the country.

Whether or not these new developments will permit more leisure and greater profits will depend entirely upon the control which the public places upon such new developments, particularly as to the organization and methods of making these wonderful facilities available for use by the public at the cheapest cost. In consideration of this factor alone, one must take into account the economic limitations which will be involved in the rapid obsolescence of present-day communication facilities.

It is considered by many that the application of these modern communication facilities will not result in a decrease in employment, but rather in an increase in employment. However, such employment will tend toward those who are qualified scientifically rather than those who are qualified manually. The person of the future may, as a result of propinquity with the everyday modern communication developments, become a far better educated thinker than the average person of today.

In the following, greater details of communications technology will be discussed in the narrower fields of telegraphy and telephony, both by radio and land wire, and of broadcasting and certain important adjuncts of our basic communications systems.

COMMUNICATION BY WIRE AND WIRELESS

Wire Telegraphy

If not the most important, probably one of the most important reasons for the progressive widening of the individual human being's perception of the world around him has been the tremendous growth in communications during the last half century. This led to a concomitant shrinkage in the size of the earth as a whole viewed from a relative standpoint, and today there is hardly a place on the surface of the globe which is not within almost immediate hailing distance, when we consider the hailing to be done by one of our many modern communication methods.

As man has learned to wrest from nature the various tools by which he enriches human experience, communication has always been one of his immediate considerations. In the days when social units consisted first of families and then of clans, beginning with the stone age, man hewed his messages onto rough slabs of rock broken from the walls of his dwelling place in the caves. Through the times of the nomadic forest dwellers who signaled to one another by means of crude marks chopped on the sides of trees and by smoke signals, down to the present when two important business houses, one in London and the other in New York, can carry on a highly technical arbitrage business with 16-second delivery from sender to addressee, the need for communications has been one of the first thoughts in the mind of man after his pri-

mary requirements of food, shelter, and clothing were satisfied.

In any approach to the communications industry as a whole, it is logical, when we are considering electrical communications, to take up first the telegraph, which was first produced in practical form by Samuel F. B. Morse.

Beginning with a very slow speed operation using hand sending and hand receiving with pencil and paper, the capabilities of Morse's early telegraph instrument were rapidly developed by means of successive inventions and improvements which greatly increased its usefulness to the public. From the early beginnings of a single-wire, ground-return, battery-sounder circuit grew the development of a duplex and then a multiplex telegraphy for manual operation. The capabilities of this system were then increased by the use of printing telegraph instruments.

Messages in the multiplex system are transmitted automatically by mechanical transmitters actuated by a perforated tape, previously prepared by a perforator having a keyboard similar to that of a typewriter; they are received automatically on printers. With this system of operation, any touch typist may be trained to be a telegraph operator in a very short time. As multiplex operators do not require the training and skill required for Morse operators, their rate of pay is about half of the rate of the Morse operators. It is necessary, however, to provide a small technical staff at each office to supervise the operation of the automatic equipment. By the use of multiplex systems it is possible to obtain not only more efficient use of existing facilities but also to reduce greatly actual operating expenses.

With the advent of the vacuum-tube repeater, based on De Forest's invention of the 3-electrode vacuum tube, which was primarily developed for long-distance telephone operation, carrier current telegraph systems, by which as many as 12 telegraph channels may be obtained from a single telephone channel, were introduced. This development greatly increased the number of telegraph circuits available for lease. The development of a telegraph printer capable of reliable operation with a very small amount of maintenance by means of which business houses could conduct their telegraph correspondence at higher operating speeds and less operating costs than for Morse operation was the next step.

The telegraph companies for whom these printers were developed, primarily, use them to connect the office of their principal customers to the telegraph offices in order to reduce the time required for the pick-up and delivery of messages and to eliminate messenger expenses. These printers are used, also, to connect the branch offices of the companies in large cities to the main office in order to give the public better service.

The telegraph field was further enlarged by the Teletypewriter Exchange Service, by means of which any subscriber to the service may communicate by telegraph printer for short periods of time with any other subscriber. The service was originally introduced with a minimum communication period of 5 minutes, which was soon afterward reduced to 3 minutes.

Many new classifications at rates lower than the full rate to attract social correspondence and to promote the use of the telegraph by the general public have been introduced. Some of the classes are greetings messages for birthdays, anniversaries, Christmas, Easter, etc; "Tourate" messages, by means of which tourists may keep their friends and relatives advised of the progress of their trips; and fixed-text messages, from fairs, expositions, and places of interest.

Prior to the World War, telegraphic correspondence in the United States was almost entirely business communications; the general public had not been educated to the uses of the telegraph for social correspondence, other than for messages of a serious nature. The classes of traffic available for business and social correspondence were the full rate for expedited traffic and night letters and night messages at rates lower than the day rates. The night classifications were offered by the telegraph companies to provide traffic for the circuits at night when the facilities of the companies would have otherwise been idle. The day-letter classification, in which messages of 50 words may be sent at one and one-half times the full rate, was established during the war period when the Government controlled telegraph operations.

The classes of international traffic available to the general public before the war were the full rate (in plain language or in 10-letter pronounceable code words), the urgent at three times the full rate charges, and the deferred (in plain language, only) at one-half the full rate charges.

Improved automatic relaying equipment has since been developed by means of which manual relaying has been eliminated. Although this automatic equipment requires the attention of skilled technicians, the cable companies have been able to reduce the personnel at relay stations to less than 25 percent of the staff required for manual relaying.

Since the war, the cable companies have greatly increased their traffic-handling capacity by increasing the speed of operation of existing cable circuits and by laying many additional high-speed cables. Additional transoceanic traffic capacity has also been made available by the large increase in the number of radiotelegraph circuits from the United States to foreign points. At the present time, the United States is con-

nected by direct radio circuits to almost every country in the world and by through cable circuits to the principal countries.

Usually, when a radio circuit was first established, the rates for radio traffic were made lower than the cable rates. The cable companies lowered their rates to equal the radio rates in order to meet this competition.

Radio Telegraphy

Up to the present, we have considered primarily telegraphy between fixed points. If we turn to radio telegraphy, we find at once that this type of communications is peculiarly adapted for use by mobile stations, such as ships and aircraft, which have no other means of communication over long distances. It is interesting to consider some of the services performed and to visualize the consequences if radio were not available.

Marine radio communications can be divided into three general classes; namely, general-message communications, aids to navigation, and distress. The handling of general-message communications between ship and shore is probably the oldest commercial radio service, as shortly after the adaptation of the use of radio by Marconi, mathematically postulated by Clerk Maxwell in 1865 and demonstrated by Hertz in 1887, a number of installations were made to permit shipowners to talk to their masters. Radio equipment was extremely varied in the early days of marine application and was of the type which created considerable interference. Aboard ship it was confined to transmitters capable of communication over relatively short distances. Need for definite rules and regulations regarding the use of this equipment and need for uniformity in conducting traffic have resulted in a series of international conferences, beginning with the Radiotelegraph Conferences of Berlin in 1903 and 1906, followed by similar conferences in London in 1912, Washington in 1927, and Madrid in 1932, the latter being the existing treaty among the principal nations of the world in regard to regulating the conduct of radio transmitters.

The use of radio as an aid to marine navigation is of comparatively recent development. The various aids may be grouped into two classes. The radio direction finder is now widely installed aboard ships and along the various coasts of the world. By means of this device the direction from which the signals of any radio transmitter approach a radio receiving station can be determined. By means of triangulation and the use of the direction finder a geographical position may be determined either by taking bearings on a single transmitter by several direction-finding stations or by taking the bearings on several transmitting stations by a single direction-finding station, the transmitters being located in known positions.

Originally, direction-finding stations were established along the coasts and any ship desiring to know its position would send a message to those stations requesting coordinated bearings, and as a result the stations on shore were enabled to advise the ship as to its geographical location. The suitability and utility of direction finders installed aboard ships have been amply demonstrated; a large number of shipowners have been encouraged to make such installations. Radio bearings were originally taken on the various radio transmitting stations along the coast, installed for communication purposes and whose positions were known. In order to provide a greater measure of safety of life at sea, a large number of radiobeacon stations have been installed by the Federal Government along our coasts for the particular purpose of sending out special distinguishing signals in order that a ship at an unknown location at sea may be enabled to take bearings on two or more of these radiobeacon stations, or "radio lighthouses", and by a simple triangulation method be enabled to fix its position.

A recent development has been the synchronization of underwater sound signals with the radio signals sent from these radiobeacons. The time of travel of sound under water is finite and is known with considerable accuracy, while the speed of travel of a radio wave is extremely high in comparison. Since the radio and sound signals are started at the same instant from the radio lighthouse, and since the velocity of travel is different, the two signals will arrive at a ship at different times. By determining the period between the two arrivals and by comparing with the velocity of sound under water, and by determining the direction from which the signal comes through the use of the direction finder, the shipmaster may determine with considerable accuracy the distance and bearings of his ship from that particular radiobeacon.

In this field, considerable advance is being made in equipment. More radiobeacon stations are being installed and advantages are taken of appropriate developments in the various communication arts to increase, so far as possible, the safety of life at sea.

The handling of miscellaneous communications between ship and shore, although being perhaps the oldest use of radio communication, has gone through a very slow period of development. The frequencies most generally used lie between 300 and 550 kilocycles, which frequencies, although having good communication characteristics, are limited in range unless considerable power is used. Further, a majority of the

ships of the world are still equipped with and are using spark transmitters, which type of transmitter is generally considered obsolete and the use of which is prohibited for all other classes of stations.

In the last 5 years American shipowners have taken advantage of the more modern developments in this art. The introduction of the vacuum-tube transmitter after the war and the quite general use of the high frequencies have made it possible for an American station to keep in radio contact with a suitably equipped ship in any part of the world, with considerably less power than previously, with a greater degree of flexibility and freedom from interference in handling radio traffic. In a number of cases, high-frequency radiotelephone equipment has been installed and through the agency of suitably equipped coastal radiotelephone stations, passengers on vessels on any of the seven seas have been enabled to conduct two-way communication with a majority of the land telephone systems of the world. The shipowners and the public in general are kept informed of the position and time of arrival of ships, and owners may correspond at will with their ships while at sea, relative to the routing of the ship and disposition of cargo, all of which is not only conducive to economy but is a definite aid in handling commerce.

A recent development of communications generally which will no doubt expand into the marine field is the radio facsimile service, or the transmission of images, by which weather maps, photographs, pictures of documents of a similar nature, and the transmission of any type of message may either be delivered aboard ship or transmitted from ship to shore.

Another development has been the provision for communications with the smaller craft operating in the vicinity of the coasts. The lower frequencies most generally used by ships are somewhat unsuitable for craft of this nature, since, in order to achieve efficient radiation, antenna structures are required which cannot be erected within the space available. The development of high-frequency communication has changed this picture and at the present time several coastal stations have been established equipped with apparatus specifically designed to handle communications with these smaller craft and to provide them with the same facility of communication with the various land telephone systems of the world as has been made available for the larger vessels. In at least one instance the very high frequencies, that is, the frequencies above 30,000 kilocycles, are also in use for this purpose, and further development is undoubtedly near at hand in this field.

The use and utility of radio for distress purposes at sea were demonstrated, and the value of radio installations on ships was brought forcibly to the public attention in 1909 in connection with the collision between the steamship *Republic* and the steamship *Florida*, in which the saving of 1,500 human lives was the direct result of the use of radio. This incident, together with the *Titanic* disaster in 1912, prompted the Congress of the United States to enact legislation requiring all ships carrying or licensed to carry 50 or more persons leaving ports of the United States to be equipped with radiotelegraph apparatus and to have at least two operators, with at least one on duty at all times. This legislation affects today a relatively small number of ships sailing from our ports. Recently the Congress has been considering new legislation to replace the Ship Act of 1910, amended in 1912, in order to bring legislation on the subject up to date. The new proposed legislation follows closely the requirements of the International Convention for the Safety of Life at Sea (London, 1929), to which all of the maritime nations of the world are now a party. The convention referred to and the proposed legislation raise considerably the standards throughout the world affecting the use of radio aboard ships for the purpose of promoting the safety of life at sea.

Under the terms of the International Radiotelegraph Convention (Washington, 1927), reaffirmed by the International Telecommunication Convention (Madrid, 1932), provision was made for the use of an automatic receiver on board vessels to maintain a watch on the distress frequency during those periods when a human operator is not on duty, this piece of apparatus to be actuated by a special radiotelegraph signal sent at the time of distress. A number of these automatic alarm receivers have been developed in foreign countries, approved by foreign administrations, and are installed in foreign ships. During the past year, this Government issued specifications for such a device for use on American ships and provided for the submission and testing of apparatus built to comply with these specifications with a view to its approval by this Government. These specifications for standards were deliberately made very high. To date, no such receivers have been submitted for test; however, a number are in the laboratories. The general installation of apparatus of this kind, if effective, should result in increasing the safety of life at sea. Instances such as that which occurred in the sinking of the *Titanic* will be avoided. It may be recalled that in this major maritime disaster another vessel was almost in sight of the *Titanic* at the time the radio distress message was sent, but unfortunately the only radio operator aboard that vessel had retired for his night's rest and knew nothing of the disaster until his return to duty the next morning.

In general, maritime communications have entered upon a period of development which should lead to greater safety of life at sea and to greater convenience to the passengers in vessels on the high seas.

Radio stations established at fixed points and used for communication with other stations likewise established are denoted by international treaty and by domestic law as "fixed stations." The actual service of communications carried on between such stations is designated by similar agreement as "fixed service." The first system of this kind installed on United States territory for regular commercial service was inaugurated on March 1, 1901, offering public radiotelegraph service between the five principal islands of the Hawaiian group, Oahu, Kauai, Molokai, Maui, and Hawaii. Today there are approximately 375 radiotelegraph stations and 40 radiotelephone stations in the continental United States, Puerto Rico, Guam, and the Territory of Hawaii, licensed by the United States Government for the purpose of rendering commercial fixed service for the general public. These stations are owned and operated by 18 American communication companies, the majority of which provide direct and expeditious means of exchanging messages by telegram or voice with several foreign countries and between the United States and the aforementioned possessions. Many additional foreign points also can be reached indirectly via these direct circuits in conjunction with the connecting radio and wire systems of other nations.

The first commercial transatlantic service was established in the year 1908 by low-frequency (long-wave) radiotelegraph stations located at Glace Bay, Nova Scotia, and Clifden, Ireland. Similar commercial stations near New Brunswick, N. J., and at Carnarvon, Wales, were completed and began regular operation on April 23, 1910. Trans-Pacific service of this kind between San Francisco and Honolulu was inaugurated during the autumn of 1914 and between Hawaii and Japan on July 27, 1915. A limited service also was established about this time between the United States and certain Central American countries. Radio communication at this period was most unreliable as compared to cable communications, and hence radio handled only a very small percentage of the United States international traffic, and had practically no effect upon cable rates.

Immediately after the World War, the United States Government adopted the policy of encouraging "direct communications" from the United States to the principal nations of the world with which the United States was engaged in commerce. By "direct communications" is meant the elimination of relays (automatic or otherwise) in countries other than the United States and the country of destination of the message.

At the same time the United States Government also fostered the policy of American ownership and control of radio companies.

These two policies were particularly important to the national defense. This action resulted in the expansion of "direct radio communication" to various parts of the world; and for the first time gave the United States a dominant position in effecting its own communications with whatever part of the world it desired and deemed necessary.

By the year 1926, the art of transoceanic radio communication had developed to such an extent that commercial photogram service was in operation between New York and London and between San Francisco and Hawaii. The principal factors in making possible this progress were the invention of the three-element vacuum tube and the practical application of high-frequency (short-wave) technique.

All domestic radio circuits employ telegraphy and, in general, are operated between principal cities of the continental United States, in connection with the established landline telegraph systems. There are a number of special adaptations for domestic radio circuits which make use of the inherent advantages of radio. For example, stations located in and near the oil fields in the South and Southwest are operated primarily for the specialized requirements of the oil industry. Similarly, there is, in the far West, a special Federal-State marketing service which operates several stations from a communication network for the expeditious handling of market information. This is especially beneficial to fruit growers' exchanges and other agricultural interests. Again, in the Hawaiian Islands the domestic radiotelegraph service is of great value in furnishing communication between the principal islands because of the difficulty of maintaining cables which are subject to serious damage by coral reefs.

The majority of commercial radio stations in the United States engaged in international and overseas communication are located near the Atlantic, Pacific, and Gulf coasts, and represent the necessary physical facilities for two-way duplex communication directly with all the important foreign countries and United States possessions.

In the fixed public press service (radiotelegraph stations limited to handling press material), the principal development appears to be the expansion of multiple-address transmission of press traffic from metropolitan centers to subscribers at a plurality of locations throughout the United States, Canada, Puerto Rico, Alaska, and Hawaii, who need only to maintain a simple receiving station and have available an employee capable of translating the telegraphic signals. A large proportion of the subscribers are broadcast stations.

The aviation radio service has made the high-speed transportation of mail and passengers over land and sea possible. Before 1929, very little use was made of radiocommunication between aircraft and ground, nor were there many radio aids to air navigation in existence. As a result, very few passengers were carried in aircraft and except under unusual circumstances no flying was conducted during bad weather. In addition, the accident rate was far above its present figure.

At the present time the country is overlaid with a network of radio aids to air navigation operated by the Government. These included radio range stations to guide aircraft from place to place, and weather broadcast stations which, as their name implies, broadcast important weather information for the benefit of all aircraft in flight. In addition there are hundreds of stations operated by air transport agencies for their own benefit and for the benefit of itinerant fliers for dispatching aircraft, exchanging information with regard to aircraft operations, and for the collection and dissemination of weather information, all of which make possible safe high-speed aircraft operation. These privately owned and operated stations comprise systems extending from the westernmost possessions of the United States to the State of Maine and from the Territory of Alaska to the Territory of Puerto Rico. Aircraft with radio equipment licensed by the United States are flown in China, across the Pacific, around South America, within Alaska, and, in the very near future, across the Atlantic. Further discussion would hardly appear necessary to show the profound effect on the life of the people of the United States caused by the availability of high-speed air transportation; this is only possible because of the widespread communication facilities.

Briefly, the classes of radio stations licensed by this Government include aircraft stations which, as the name implies, are those stations installed aboard aircraft; aeronautical stations which are those located on the ground for the purpose of establishing two-way communication with aircraft; aeronautical point-to-point stations which are for the exchange of information between points on the ground with reference to the operation of the aviation industry, and airport stations which are those licensed for the control of air traffic in the vicinity of an airport and to assist aircraft in making safe landings during periods of thick weather. The Government and various commercial agencies interested in aviation maintain a continuous study of the use of radio in this field, and as advances in technique are made changes in appropriate rules and regulations are authorized, in order that those traveling in person or shipping their goods by means of aircraft may be afforded every advantage of the most modern technique in their protection.

Emergency Services

Of the various classes of stations in the so-called "emergency service", the police radio stations are best known. They have increased the safety of life and property on the ground and in a measure have reduced the prevalence of crime by making apprehension and punishment more certain. The two major classes of police stations are those authorized for communication between State- and municipal-police headquarters and policemen in the field. By use of radio it has been possible to give better protection with less personnel than was formerly the case. While it might appear that this would tend to reduce employment, it has not done so, since men who have been released from patrol duty by the installation of radio equipment have been assigned to other necessary duties in the city or State installing radio and as a result those cities or States are better protected than ever before with an immaterial increase in expense.

A new class of police radio service has been recently established which has not as yet demonstrated its capabilities. This new service consists in the establishment of a network of radiotelegraph stations for the use of various police departments of the Nation. It will provide for the dissemination and collection of information with respect to crimes with greater rapidity and over a wider area than was economically possible by the use of the existing means of communication. It is expected that this new service will result in a further decrease in crime.

As in the case of aviation, the Government operates in cooperation with the various police agencies throughout the Nation in order that the public may be enabled to receive the benefits of the advances in the art of radio communication as rapidly as possible.

Another class of station in the emergency service is known as "special emergency." This class of station was originally authorized for use by the large power distribution agencies at those times when the regular systems of communication were interrupted due to storms or other causes. The original purpose has been broadened until now stations of this class are not only used by power distribution systems but also by water distribution systems, for the protection of forest areas and for the handling of communication in time of emergencies such as floods or earthquakes. This class of station has repeatedly demonstrated its value and its effects on the general welfare are so apparent that no further discussion need be added.

The final class of station under the emergency service is known as "marine fire." One specific frequency has been set aside for the use of this class of station at any appropriate place within the United States.

The purpose of these stations is to communicate with fireboats patrolling the various harbors. Without radio communication it is the common practice for a fireboat to remain tied up at a dock until an alarm of fire at sea or along the water front is received by telephone, at which time the fireboat departs to the scene of the conflagration. If the alarm be found to be false or if the fire is brought under control by means of land fire apparatus or by other agencies, there are no means of reaching the fireboat until its arrival upon the scene. In the interim the water front is absolutely without protection of this essential piece of fire-fighting apparatus. In addition to many miles of steaming saved by means of the use of radio, a greater measure of protection can be obtained with existing floating fire apparatus and the cost of equipment is usually saved many times by the savings effected in the cost of fuel.

Special Services

Another class of station which is little known is that known as "geophysical", which term refers to those radio stations used in investigating the topography of the underground strata of the earth. The major use to which these stations have been put is in the survey of territory believed to be underlaid by strata of oil bearing sands. By their use much money has been saved in fruitless drilling and many hitherto unsuspected oil fields have been discovered, both of which factors have contributed to the present low cost of motor fuels. The use of these stations is invaluable in the determination of new oil fields which contribute to potential fuel reserves which may be made available in time of national emergencies.

Another kind of station is known as "motion picture", operating in the temporary service. This class of station is installed for the purpose of providing communication in connection with the photographing of scenes laid in the remote parts of the country or embodying large bodies of personnel. Through this communication, the production of many outstanding motion pictures has been made feasible.

The rapidly growing development of facsimile, the principles of which have been known for many years, but whose practical application has been only recent, opened up interesting vistas to the far-seeing business executive. With present apparatus, it is not only possible, but practical, to use facsimile transmission as a specialized tool of communication which will increase vastly the speed and efficiency of record communication. For example, it is possible with facsimile equipment to transmit at a distance, by wire or by radio, whole pages from ledger books, pages of checks with authenticated signatures, bills of lading, invoices, and the multitude of other records which are in everyday use.

Facsimile can also be used as a business adjunct in the home of the busy executive, where it is possible for him to receive daily reports typed and signed at his headquarters and speedily made available with infallible accuracy. This may also be supplemented by business news service in his home, also supplied by wire or radio, and the eventual transmission of entire newspaper pages so that he may carry out his important business, financial, and social negotiations at a distance. The service itself is technically available, and its ultimate growth and use will depend largely upon its simplification and quantity production with resulting lower costs.

Telephony: Wire and Radio

The importance attained by telephony in meeting the industrial, commercial, agricultural, financial, economic, social, and other needs of our present-day civilization rests largely upon the fact that it has made possible complete two-way intercommunication between practically all the telephones of this country and between over 90 percent of all the telephones in the world, with a relatively short delay in the establishment of a desired connection, with ample volume of transmission, and with such a high quality of reproduction of the transmitted voice that the speech characteristics of the talker are readily recognized. Further, the speed of transmission, varying with the circuit facilities employed from 10,000 miles per second to almost its theoretical limit of 186,000 miles per second (the velocity of light in vacuo), is so great that ordinary conversations can be maintained almost as they would be face to face without even noticing the fact that the transmission is not instantaneous.

In 1875 the conception of a great idea, the electrical transmission of the spoken word, began to germinate in the brain of Alexander Graham Bell, who, among many others, was a pioneer in communications. At that time Bell was working on another invention, the harmonic telegraph, by means of which he hoped to send several telegraph messages simultaneously over the same wire. While experimenting with a transmitter built for this purpose he first noticed that the sound produced by the feeble twanging of a vibrating reed could be reproduced as sound by the receiving device.

During the succeeding 10 months further experimenting led to the development of modified apparatus, and on March 10, 1876, the first spoken words, uttered by Bell, were electrically transmitted from one room to another in the same building, where, reproduced as sound by the receiving device, they were plainly heard by Mr. Bell's assistant to whom the first telephone message: "Mr. Watson, come here; I want you", was addressed.

The original apparatus consisted essentially of a transmitter and a receiver, both embodying the principles of the present-day telephone receiver, the former being very inefficient as compared with present-day transmitters. It is interesting to note, however, that a replica of the original Bell apparatus was actually used in the demonstration of transcontinental telephony with the aid of amplifiers making up for this lack of efficiency as well as for the huge incidental circuit losses.

While the commercial and social possibilities of Bell's invention were soon realized, many step-by-step advances were necessary to apply it in practice and to meet new conditions and requirements as they arose. The important early requirements which had to be met before service could be offered were as follows:

The development of a more efficient transmitter.

The development of signaling devices.

The design of switchboards for interconnecting any two lines.

By 1880 there were over 30,000 telephones in the United States, principally in the larger cities. The increase in the number of telephones brought with it numerous problems such as:

The need for improved switching devices.

The increase in number of wires carried on the same pole line, leading eventually to the development of telephone cable.

The resulting cross talk and the need for its elimination by the use of two-wire lines and by their transposition.

The telephone industry is now the third largest public-utility industry in the United States, being exceeded only by steam and electric traction and by the electric, gas, power, and light industries. Its magnitude is indicated by the following statistical data as of December 31, 1934, and by the three tables which follow:

The telephone industry

Approximate total investment in plant and equipment	[1] $4,750,000,000
Gross operating revenue	980,000,000
Number of telephones	[2] 16,968,845
Miles of wire	86,800,000
Local service	71,138,000
Toll service	15,662,000
Average completed conversations per day during 1934	73,400,000
Local	70,980,000
Toll	2,420,000
Number of employees	[3] 298,000
Additional employees engaged in research manufacturing	[3] 27,000

[1] Not including $150,000,000 invested in plant and equipment of important manufacturers of telephone equipment.

[2] Maximum number of telephones in use Dec. 31, 1930, 19,613,769.

[3] Combined number of employees Dec. 31, 1929, 530,000.

Telephone development in United States by years 1876 to date

Dec. 31	Estimated population	Total number of telephones, United States	Total number of telephones per 100 population, United States
1876	46,193,000	2,593	0.006
1880	50,952,000	47,880	.09
1885	57,348,000	155,751	.27
1890	63,769,000	227,857	.36
1895	70,293,000	339,502	.48
1900	76,938,000	1,355,911	1.76
1905	85,028,000	4,126,924	4.85
1910	93,282,000	7,635,367	8.19
1915	101,262,000	10,523,497	10.39
1920	107,390,000	[1] 13,329,379	12.41
1925	115,784,000	16,935,918	14.63
1930	123,500,000	20,201,576	16.36
1935	127,300,000	17,423,871	13.69

[1] Includes an adjustment of 82,000 (minus) to agree with 1920 station-development census.

Estimated completed telephone conversations—daily—years 1880 to 1935, inclusive

Year	Total United States			Year
	Exchange	Toll	Total	
1880	237,000	2,000	239,000	1880
1885	629,000	9,000	638,000	1885
1890	1,211,000	[1] 6,000	1,217,000	1890
1895	2,150,000	54,000	2,204,000	1895
1900	7,689,000	193,000	7,882,000	1900
1905	21,160,000	516,000	21,676,000	1905
1910	35,299,000	862,000	36,161,000	1910
1915	43,719,000	1,101,000	44,820,000	1915
1920	50,207,000	1,607,000	51,814,000	1920
1925	64,850,000	2,450,000	67,300,000	1925
1930	80,225,000	3,295,000	83,520,000	1930
1935	73,440,000	2,560,000	76,000,000	1935

[1] Reports incomplete prior to 1891.

Changed Population Characteristics.—When the telephone was invented the population of the United States was overwhelmingly rural but it is now only 44 percent rural. The corporate limits of such cities have in many cases been practically ignored in the development of suburban areas, many of which have themselves grown into separately incorporated towns and cities, the whole often forming a continuous urban community. In 1930 the United States census reported 93 cities as having populations of 100,000 or more with an aggregate population of over 36,000,000. It also recognized 96 "metropolitan districts" composed of one or more central cities, together with the surrounding towns and villages, thus forming one area having more or less common social, economic industrial, and financial interests. In 1930, these 96 metropolitan districts had a combined population of almost 55,000,000, 5,000,000 more than the entire United States population when the telephone was invented.

Telephone development, until the depression, much more than kept up with the increase in population. It has been designed to the end that telephone service

will be offered to every community, large or small, in accordance with the local requirements, the equipment naturally varying according to the size and telephone development of the area served.

At one extreme we find many rural areas served by multiparty "farm" lines equipped with local battery telephones and magneto ringers and signals, the lines in most cases being connected for switching service to the next nearest exchange.

At the other extreme is the New York-northeastern New Jersey metropolitan district, a description of which follows:

More than a sixth of all the telephones are concentrated in a section which composes only about one twelve-hundredth of the land area of the continental United States.

This section, as defined by the United States Census Bureau, is the New York-northeastern New Jersey metropolitan district, generally called the New York metropolitan area. It includes large sections of those two States and a small part of southwestern Connecticut, comprising a total of 2,514 square miles, a territory twice the size of Rhode Island. An exact circle enclosing such an area would have a diameter of about 57 miles. In its actual form, and using the Borough of Manhattan, New York City, as the center, the longest axis is approximately 95 miles and the shortest 40 miles.

Within this area are approximately 300 incorporated communities. Among them, in addition to New York City with its 5 boroughs and population of 7,000,000, are Newark with about 450,000, Jersey City with more than 300,000, 3 other cities with well over 100,000, 8 with over 50,000, 15 with over 25,000, and more than a score with over 10,000.

The area's aggregate resident population—10,901,424 according to the 1930 census—exceeds that of any State except New York. Computed on the basis of that census, it contributes nearly an eleventh of the population of the entire country.

Approximately a sixth of the average daily telephone conversations originate from the telephones in this area * * *. The area's telephones which serve these myriad requirements numbered as of July 1, 1934, about 2,255,000, of which 1,478,000, or nearly two-thirds were in New York City. Manhattan alone had about 817,000 * * *. The average daily telephone conversations during the first half of 1934 totaled approximately 9,183,000, or about 382,625 an hour.

Subscribers' telephones in the general metropolitan service area, which includes some sections not within the metropolitan census district, are grouped under 478 central office designations, and are served by 378 central offices, an addition of 138 since the war. New York City, with 160 central offices, has 192 designations in use, as many as the aggregate in the 3 next largest cities of the United States. The designations as a whole exceed those in the 10 largest cities other than New York.

Employed within the area in telephone service are approximately 48,000 men and women * * *. About 60 percent are women. About 35 percent of the employees are engaged in plant work, and about 30 percent are operators.

About 1,210,500 telephones, or more than half of the area's total, are served from dial central offices, of which there are 129 * * *. The dial system is regarded as providing special advantages in serving a cosmopolitan population.[2]

[2] Excerpts from an article by Kirtland A. Wilson, Transmitter, Chesapeake & Potomac Telephone Co., March 1935.

From the above it will be seen that there have been developed in the United States local telephone systems for meeting varying population requirements.

Toll Service.—The first period, up to 1900, marks much substantial progress in extending the range of commercial transmission beyond local areas. Beginning with the 2 miles between Boston and Cambridge in 1876 and from Boston to Providence, a distance of 45 miles in 1880, the range has been gradually extended. In 1892 commercial service was offered between New York and Chicago, a distance of 900 miles. This marked the economic distance limit until the next important development, "inductive loading", became available.

Inductive Loading.—The principle underlying the inductive loading of telephone circuits was patented in 1900. The purpose of such loading was to compensate for the effects attributable to electrostatic capacity between the wires of a circuit, thus securing a reduction in attenuation, and at the same time equalizing the attenuation, thereby greatly extending the distance range.

Loading was first applied to open wire circuits including the two "side" circuits and the "phantom" circuit derived from two pairs of conductors. This made it possible in 1911 to extend service to 2,100 miles (New York to Denver) and 2 years later to 2,600 miles (New York to Salt Lake City).

Loading was next applied to cable conductors for which the normal attenuation was far greater than for open wire circuits.

In large cities it had already been found that the attenuation even on long trunks between central offices unduly decreased the transmission, this being overcome by loading. It had also been found necessary to reduce to a minimum noise and cross talk through improvements in construction, manufacture, and installation of telephone cable to eliminate capacity unbalances. The mutual influence of adjacent circuits was largely eliminated by twisting the wires of a conductor pair about one another and similarly by twisting the pairs of a four-wire group of "quad", the length of the twist being varied for the different pairs to give full effect to the twisting.

Even more particular attention naturally has to be given to the design, manufacture and installation of toll cable in which the prevention of cross talk, noise, and other effects is rendered much more important especially since the very general introduction on long circuits of telephone repeaters by which such effects are also amplified.

The first application of loading to underground toll cable circuits was made in 1906 between New York and Philadelphia, a distance of 90 miles. This was extended in both directions to Boston and to Wash-

ington, a distance of 455 miles, the whole being completed in 1913. Designed before the advent of the telephone repeater, the cable was made up in part of heavy gage conductors (No. 10 American wire gage) and a heavy type of loading to furnish commercial service between the termini. Some sections of this cable are still in use.

The advent of the repeater and associated developments practically solved the problem of long-distance transmission by toll cables and removed all distance limitations.

Means first had to be devised for associating the telephone repeater with the circuit to which it was to be applied for two-way communication, the repeater being essentially a one-way device. This was accomplished in various ways, generally involving the use of balancing networks matching in electrical characteristics those of the line in order to prevent disturbing influences, especially "singing" of the repeater. Electric filters were employed to limit the frequency range over which it was necessary to balance line and network.

Potentiometers were found necessary to control the repeater gain within specified limits to prevent excessive amplification with attending increase in cross talk, noise, etc. Voice frequency signaling systems were developed and applied. Among the further important developments were:

Means for equalizing attenuation throughout the frequency range to be transmitted.

Regulators for automatically compensating for variations in repeater gains resulting from line or cable temperature variations.

Echo suppressors especially for use on very long lines.

Carrier Systems.—The development of carrier telephone and telegraph systems has already materially increased the total circuit or channel mileage available for use. In brief, carrier systems, almost universally employed in broadcasting, are based upon the following fundamental principles:

1. The continuously varying electrical currents corresponding to speech or signaling may be impressed upon a single frequency "carrier" current lying outside the frequency band to be transmitted by the process known as "modulation."

2. That such modulated carrier currents may be superposed and transmitted together.

3. That they may be separated from one another at the distant terminus by means of electrical filters transmitting only one of such modulated currents.

4. That each of the modulated currents may be separately demodulated and transformed into the sound or signal which it is intended to transmit.

5. That transmission losses may be overcome by the aid of repeaters.

6. That any loss in the quality of the transmission may be restored by various refinements which have been developed.

Toll service is handled in various ways, depending upon various factors. In the case of very large toll centers separate offices have been established for handling this important service. Quoting from the article previously referred to:

> The long-distance office in New York itself is a battery of offices which compose the largest long-distance center in the world. It is the focal point of many important cities in the United States. Through it flashes the traffic which is handled over the radio-telephone circuits to Europe and other overseas points. It is the principal control point for the great radio broadcast chains. It houses the largest teletypewriter exchange. All private wires from New York to other cities, whether telephone, teletypewriter, or telegraph, are brought through this building.
>
> From the toll and long-distance offices of the city a vast network of circuits fans out into the surrounding territory, for it is the regional center for a large section of the Northeastern States. Crossing from Manhattan under its surrounding waterways are 46 toll and long-distance cables, with nearly 18,000 circuits. One of many notable engineering features is the permanent subway cable crossing under the Harlem River, between Manhattan and the Bronx. Through it pass not only the toll and long-distance highways between New York City and New England points, and toll routes to northern suburban sections, but also the paths through which the greater part of the calls between the country at large and the Northeastern States are dispatched.

General Toll Switching Plan.—The removal of distance limitations from toll service through the advent of the repeater and associated developments made it possible to plan a systematic plant lay-out for rendering such service between any two telephones in the United States with a minimum of delay in the establishment of connections, with an adequate volume and quality of transmission, and with very material overall economies.

In brief the plan consists in providing a limited number of "regional centers" (eight at present) each directly serving one of the regions into which the country is subdivided. The places selected for regional centers, strategically located to serve the country as a whole, were New York, Atlanta, Chicago, St. Louis, Dallas, Denver, Los Angeles, and San Francisco. Each of these was planned to be interconnected with every other regional center by a group of direct circuits thus forming the basis of a country-wide network.

Next were selected some 140 "primary outlets" each of which was planned to have direct circuits to one or more of the regional centers and direct circuits to all toll centers in the area for which it is the primary outlet. Each of some 2,500 toll centers in turn was

planned to have direct circuits to all "tributary" outlets. In addition there have been provided a number of secondary outlets and secondary switching points furnishing respectively alternate routes for toll centers for reaching regional centers and providing more direct routes, thus reducing back-haul for intra-area business. In addition the plan calls for direct circuits between any other points which may be justified by the amount of traffic to be handled.

As a result of careful selection of the regional centers, primary outlets, and toll centers and provisions for direct circuit groups between other important points 80 percent of long-haul toll calls are now handled without any intermediate switching and 17 percent with one intermediate switch.

In order that the transmission between any two points in the country over a circuit routed in accordance with the general toll switching plan should be satisfactory, standards were established for each class of toll circuit, that is, for toll circuits between toll centers and primary outlets, between primary outlets and regional centers, etc. These standards provide satisfactory overall transmission for connections between any two points in an operating area, with an economical division of the total transmission loss between the different toll circuits entering into the connection. Generally speaking, these same circuits form parts also of very long connections, switching at primary outlets or regional centers to long circuits running to other parts of the country. In order that satisfactory transmission may be given under these conditions, it is necessary that severe requirements be applied to the very long circuits with the result that they must be designed and maintained with great care and coordination throughout their entire length. It is also necessary that transmission gain be inserted at points where circuits are connected together, and therefore that the characteristics of the shorter circuits be such that they do not limit the possibilities of inserting such transmission gains. The application of these various complex requirements for toll circuits, in order that they may form satisfactory links in any connection, short or long, in the nation-wide toll telephone network, is greatly facilitated by the systematic character of the general toll switching plan, and by the recommendations as to minimum performance standards which that plan contains.[3]

Until recently, the method generally used for inserting transmission gain on through connections of toll circuits was by means of repeaters associated with the cord circuits at the intermediate switching points. About the time that the toll switching plan was established, there was made available an improved method by which the gain of repeaters permanently inserted in the toll line is automatically adjusted at the switching point when the toll circuits are connected together. These improved arrangements were scheduled for application as circumstances warranted to the regional centers and primary outlets. As the present time they have been applied to all of the regional centers and about half of the primary outlets and about 95 percent of the switched connections requiring gain at the switching centers make use entirely of this improved method.

[3] Technical Developments in Connection With the Toll Service of the Bell System, H. S. Osborn, American Telephone & Telegraph Co., 1935.

* * * The transmission requirements applied to the different classifications of circuit for best results vary with the availability of further technical developments. For example, in the future the improved high-speed circuits made possible by the application of carrier to cables will result in modifications of the general toll switching plan, resulting in improvements of transmission over all switched connections and in economies in circuit design through liberalizing the transmission requirements for certain routes, particularly the circuits between toll centers and primary outlets.

Finally, another advantage of the general toll switching plan lies in the fact that it has offered a basis for routing toll circuits in such a way as to provide for the most economical plant design especially through the concentration of large numbers of toll circuits on a single route for which telephone cable or open wire carrier circuits are specially adapted. Increasing economies were also realized by the concentration of repeaters required on switched connection at a small number of points, this concentration leading to operating economies as well.

Relation of Telephony to Broadcasting.—Radio broadcasting as organized today depends almost completely upon wire facilities. The following description is contained in a pamphlet [4] on this subject by an officer [5] of one of the broadcasting companies.

"It is to the telephone, not to radio, that we owe the development of the equipment whereby speech and music are made available for broadcasting.

More than this, it is the telephone wire, not radio, which carries programs the length and breadth of the country. John Smith, in San Francisco, listens on a Sunday afternoon to the New Philharmonic orchestra playing in Carnegie Hall. For 3,200 miles the telephone wire carries the program so faithfully that scarcely an overtone is lost; for perhaps 15 miles it travels by radio to enter John Smith's house. And then he wonders at the marvels of radio.

But what about programs from overseas? Here indeed wireless telephony steps in, but not broadcasting in the ordinary sense. The program from London is telephoned across the Atlantic by radio, but on frequencies entirely outside of the broadcast band.

Important developments that are likely to be socially significant during the near future—

(*a*) Inventions that are in existence but undeveloped.

1. *Further development of dial switching equipment for local service in urban centers, including new types of equipment and improvement of old types.*—It is believed that, especially in metropolitan dial areas, there will be a further development of so-called extended area or extended scope service whereby subscribers in outlying areas are given access to all telephones located in specified larger areas.

[4] Broadcasting: A New Industry, Harvard Alumni Bulletin, Dec. 18, 1930.

[5] Broadcasting Network Service, Mar. 1, 1934, p. 10. The officer referred to was H. A. Bellows, formerly vice president of Columbia Broadcasting Co., president of Northwestern Broadcasting Co.

The advantage of such a service to the subscriber is that it permits him to make direct calls without the intermediary of an operator, and for this reason it usually provides a faster and more accurate service, if the mechanical installation is good.

2. *Construction of first continuously loaded trans-Atlantic telephone cable.*—This cable, which was made a definite project several years ago, has been deferred on account of the depression, and also pending the development of a demand for increased service. If and when this cable is installed, it will afford another means of direct connection between individual telephones in this country and individual telephones abroad.

3. *Application of carrier telephony to existing telephone toll cables and very high frequency carrier for existing open-wire lines.*—With the experience gained in the technique of carrier systems and the development of a new type of amplifier tube, more powerful and more stable, it is indicated that the use of carrier telephony will be greatly extended by its application to cable circuits to which it has thus far only been applied on an experimental basis. It is also plainly indicated that carrier systems with a much wider frequency band will be applied to open-wire circuits. It is expected that these developments will affect existing construction. The development of carrier telephony to cables will provide additional facilities for the use of the public.

4. *Feedback amplifier with improved stability and gain characteristics.*—This amplifier it is hoped, will considerably improve the service to the public over long distances.

(*b*) Inventions that are in use only to a limited extent.

1. *Dial exchanges in rural communities.*—These are in general unattended with dialing trunks to the next nearest exchange of which they are tributary and at which operators are available for handling toll and other service calls. The increased use of dial exchanges in rural communities will tend to improve the service rendered to the public in such communities and more nearly approach the grade service available in urban communities.

2. *Possible development of very high efficiency electromagnetic receivers in combination with transmitters of the same type.*—Such a development would considerably improve the fidelity of transmission, by eliminating another cause of distortion in transmission, and would thus provide a higher grade of service to the public.

(*c*) Developments that probably will be made.

1. *Very high frequency coaxial cable carrier systems for deriving a very large number of telephone and telegraph channels and a very broad transmission frequency band for television.*—A very high frequency type of carrier has been planned for use in combination with coaxial cables, the first of which is now being installed for experimental use between New York and Philadelphia. The coaxial cable affords an all metallic conducting path, the central conductor being a wire specially insulated from the enclosing conducting cylinder, which offers a very high degree of shielding from without and within.

It is proposed to employ a separate coaxial cable for each direction of transmission, thus necessitating the use of two cables for two-way service with means for association of the various channels at both ends to form the equivalent of two-way circuits.

The width of the frequency band for which the cables are being designed is at least 1,000,000 cycles, ample for 200 separate telephone channels or some 2,500 telegraph channels or combinations of both. The cables will also be tested in television.

2. Television by radio transmission.

3. It is also indicated that much progress will be made in the direct handling of toll calls by local operators in manual central offices and by dial operators in dial offices, via direct circuits to the points called, or via a group of circuits to such points with automatic selection of an idle circuit, or via tandem or toll switchboards. Indications are that this method will be extended to more and more distant points for which direct circuits are provided, with attendant speeding up of the service and reduction in costs.

4. *The development of a point-to-point television service to supplement the telephone.*—Such a service, which has already been tried experimentally in Germany, would provide facilities whereby two persons talking to one another by telephone would, in addition to hearing each other's voices, also be able to see one another at the same time. Such a service, providing as it would the opportunity to see facial expressions, as well as to hear changes in voice tones, would undoubtedly permit the readier exchange of thought and ideas, and lead to the quicker solution of mutual problems between individuals who are not able physically to be face to face.

In Europe considerable progress has been made in the direction of complete national automatic networks, automatic operation having been extended successively from the large cities and towns serving as centers even to the smallest tributary rural communities. The interconnecting trunks between these centers are designed to permit direct dialing and ringing, the automatic insertion of repeaters where necessary, the alternate routing of calls, zone metering, etc.

Transoceanic Telephony.—Transoceanic telephone service, utilizing radio to span the Atlantic, was opened to the public on January 7, 1927. Low-frequency

(long-wave) stations were used, which were supplemented by high-frequency (short-wave) stations on June 27, 1928. This combination of low and high frequencies provided a considerable increase in reliability and continuity of service. Intercontinental and overseas commercial telephony has steadily expanded from that time until today more than 60 countries may be reached by telephone subscribers in the United States. Some of the countries which are directly connected by radiotelephone circuits with the continental United States are England, Bermuda, Bahamas, Puerto Rico, Santo Domingo, Jamaica, several Central American nations, Peru, Argentina, Brazil, Venezuela, Colombia, Hawaii, Japan, and the Philippines.

There exists certain characteristics inherent in international radio communication which are mentioned here as being of possible interest. It is obvious that differences of time in various parts of the world will affect operating plans and will control the flow of traffic. For example, on circuits between New York and Europe, the greatest daily activity occurs in the forenoon (New York) during the business hours which are common to both regions. On international telephone circuits, difficulties in the use of different languages must be overcome. A further complication arises when circuits are interrupted or delayed because of interference from foreign radio stations suddenly operating on or near the frequency of an established circuit. Matters of this kind require international correspondence, explanation, and agreement in order to restore normal conditions. In conclusion, it may be mentioned that the volume of international message traffic has been shown to vary closely in direct proportion to the volume of export and import trade between the United States and other nations. Also during the principal holidays each year and in periods of international crises the number of international telephone calls have shown a substantial gain.

Mass Communication

Broadcasting—Aural

The development of broadcasting is very closely associated with the economic, political, and social history of the past 15 years. The system, methods of operation, and means of financing operations as they exist in the United States today should be considered as the almost inevitable result of the growth of an instrumentality for directly serving the public in a democracy where initiative and freedom of speech are fundamental.

The transmission of intelligence without the aid of wires by means of so-called "wireless telegraphy" was an accomplished fact in 1900, and the human voice was transmitted by radio on various occasions subsequent to 1911. It was not until 1920, however, that regular programs were broadcast for the reception of the general public.[6] By March 1, 1922, there were 60 broadcast stations licensed and in operation in the United States.[7]

Because of inadequate legislation, the industry had fallen into a state of chaos before 1927 as the then-existing law (Radio Act of 1912) did not give the Secretary of Commerce (who was charged with the enforcement of the Act) sufficient authority to designate the frequencies, locations, and power of broadcast stations. Licenses had to be issued to all applicants without regard to ability to render service or construct and operate satisfactory equipment. As a result of this situation, by 1923 there were 573 stations and the peak was reached early in 1927 when there were 732 stations in operation.

Coincident with the growth in the number of stations was the increasing number of receivers in the hands of the general public. In February 1922 the Secretary of Commerce released the following statement: "The Department estimates that today over 600,000 persons possess wireless telephone receiving sets, whereas there were less than 50,000 such sets a year ago." It was estimated that by 1927 the number of receiving sets had grown to 6,500,000.[8]

The invention making broadcasting possible and providing the foundation on which practically all forms of communication rest today was the three-element vacuum tube invented by Dr. Lee DeForest in 1906. It was intensively developed during the war for use in radio equipment for military communications and these tubes further perfected made possible the first broadcast transmitters and were used in part of the receivers.

Matching strides with the increase in the number of stations and receivers were improvements in transmitter design and increases in station power. The first transmitters were very crude affairs when compared with those in use at the present time. The power output was low, the frequency unstable, and the percentage of modulation below that now considered necessary to make the best use of the power. In 1922 the majority of transmitters were of 100 watts power or less and few exceeded 500 watts power. Microphones and speech amplifier equipment were such that the transmitted signal was of relatively poor quality. As the need for better quality programs increased, broadcasters realized that the equipment in use did not transmit a signal which sounded natural

[6] Chronology of the Development of Radio, 1936 Broadcasting Yearbook.

[7] Broadcasting in the United States, published by National Association of Broadcasters.

[8] Estimates by McGraw-Hill Book Co., Publishers of Electronics and Radio Retailing.

when received and there was a continual improvement in the standards of equipment used. It was also found possible to increase the transmitter power without sacrificing the quality of the signals transmitted.

In step with the development in transmitters was the continued improvement in receivers. The first receivers were small affairs using either a crystal detector or an "audion tube" and reception was only obtained through the use of headphones. When tubes were used numerous batteries were required. Within a few years receiver engineers were able to place in the hands of the public instruments which employed several tubes and operated small loud speakers. These receivers gave poor quality of reproduction judged by today's standards; they required numerous unsightly and inconvenient batteries, were not selective and were frequently rather temperamental and difficult to operate. About 1924 "B eliminators", which replaced part of the receiver batteries and drew their power from the house lighting circuit, were introduced. With the advent of the first entirely alternating-current operated receiver in 1925, the industry was given a great impetus toward a wider market. Today the broadcast receiver is a standardized piece of equipment which is manufactured in specially equipped plants and assembled on a production line similar to those developed in the automobile industry. The present receiver is so simple to operate that a child can easily tune in programs. The quality of reproduction is such that with the best high fidelity receivers it is very difficult to discern the difference between the received program and the original rendition in the studio.

The early programs consisted of phonograph records; musical selections, both vocal and instrumental; news; broadcasts of sporting events; etc. Prior to about 1924, little thought was given to program material as the listening public was much more fascinated with the idea of receiving stations at great distances and the quality and type of programs was of secondary consideration. However, with better transmission facilities and receivers, the public gave increasing attention to the programs received. Early programs were usually presented by performers who gave their service gratis for the thrill of it or the name of having performed on the radio. As public interest in and appreciation of good programs grew, stations acquired regular staff artists, announcers, and program directors, who were paid for their services. This permanent station personnel was then able to develop a technique distinct to broadcasting and to edit and present better programs.

The first broadcasting chain was formed in November 1926 for the purpose of distributing a high class of broadcast program service. The development of this chain presented a Nation-wide system of distribution for a single program, making it possible to obtain the services of better artists and musicians. Another chain was founded in 1929, supplying a second chain program service on a national basis, and in 1936 a third national chain was established. There have been several other chains of local or regional character established. Programs, when broadcast by a modern transmitter and received and converted back into sound energy by a good receiver, are entirely satisfactory for the enjoyment by the general public of the best musical and dramatic events. Programs originating in foreign countries are received at specially equipped receiving stations and rebroadcast by domestic stations. In this way events of international interest can be brought to the listener's fireside.

Broadcasting has been notable in its service to the public in many ways other than through the presentation of musical programs. It makes possible the bringing to the public of play-by-play eye witness descriptions of important athletic and sporting events. Notable as an illustration of this type of event was the first regularly established coast-to-coast network which was used to broadcast the football game in the Rose Bowl, Pasadena, Calif., on January 1, 1927.[9] Broadcasts of speeches, debates, and discussions of various subjects are an everyday part of our broadcasting activities. It is now a major factor in presenting the case of political parties to the electorate

The present phase of broadcasting may be considered as dating from the signing of the Radio Act of 1927 by President Coolidge on February 23, 1927. This act created the Federal Radio Commission with powers to classify radio stations and regulate radio communications in all forms. This body immediately began the difficult task of bringing order out of the chaos which existed in the hours, power, and frequencies in use by the broadcast stations at that time.

The Federal Radio Commission was succeeded in 1934 by the Federal Communications Commission, created by the Communications Act of 1934, which, so far as broadcasting is concerned, has practically the same powers as its predecessor. At present broadcast stations are classified according to class of service, whether local, regional, or national in coverage, appropriate amounts of power assigned to various stations according to class, and operation authorized on frequencies in keeping with the class of service and licensed power of each station.

As of July 1, 1935, there were 623 broadcast stations, of which total 421 were operating simultaneously at night.[10] These stations are assigned to 90 of

[9] Chronology of the Development of Radio, 1936 Broadcasting Yearbook.

[10] First Annual Report, Federal Communications Commission, 1935.

the 96 10-kilocycle channels between 550 and 1500 kilocycles, inclusive. The other six channels are reserved for exclusive use of Canadian stations.

Recent developments in the receiver industry are more in the nature of improving inventions which were applied to equipment which has been generally in use for several years. Probably the most outstanding basic developments which affect the receiver are the superheterodyne circuit, the multigrid tube and automatic volume control. Effective automatic volume control was possible only after the adoption of the multigrid tube, but its subsequent development should be considered as a separate step in the perfection of the receiver as we know it today. The multigrid tube made possible the commercial development of more sensitive and selective receivers which extended the distance at which the public could obtain satisfactory broadcast reception from existing stations. A fourth important step in receiver development was the perfection of the alternating current operated tube which made it possible to operate the receiver with power taken from the house lighting circuits.

Present trends in the design of broadcast receivers are toward an increased frequency range thus allowing the use of only one receiver to cover the major portion of the radio frequencies in use for communication, and variable selectivity or band width control which allows the user to render the tuning very sharp in locations where interference is severe or signals are weak, or, the tuning can be made broad for the reception of high fidelity (more natural) signals.

There has been an increasing interest recently in the development of receivers to operate from 32-volt farm lighting plants and from 6-volt storage batteries. These receivers can then be used in out-of-the-way farm locations where ordinary electrical power is not available. A wind-driven generator has been developed for charging the 6-volt storage batteries, thus providing for continuous satisfactory operation of the radio receiver at a reasonable cost.

An important recent phase of broadcast receiver development has been the introduction of automobile receivers. Some understanding of the magnitude of this branch of the industry may be gained from the following fact: That during the year 1935, approximately 1,000,000 automobile receivers were sold, these sales accounting for 18 percent of the total retail volume of radio receiver sales for the year.[11]

That the broadcast industry is a major industry is amply demonstrated by the following figures: During the year 1935 there were approximately 5,500,000 receivers sold at a retail value of $302,000,000. The greatest sales for any 1 year to date were for the year 1929 with a total retail value of approximately $592,000,000.[11] The number of families owning radio receivers as of January 1, 1936, was approximately 22,869,000. About 10 percent of families owned two or more receivers and there were in addition about 3,000,000 automobile receivers in use.[12]

Comparisons of the average retail price for 1933, 1934, and 1935 indicate a continuous increase. Thus, the average retail price for the 1935 receiver was approximately $55 as compared with $34.39 in 1933.[12] This indicates that the public is continually seeking better receivers. It should also be noted that of two receivers manufactured, one in 1933 and the other in 1935, to sell at the same retail figure, the 1935 instrument is far superior with respect to selectivity, quality of reproduction, etc.

The broadcast receiver industry alone, not considering its suppliers, accounts for the employment of approximately 85,000 persons at the peak of the production season.[13]

An understanding of the magnitude of the undertaking involved in the operation of the broadcast stations may be gained from a study of the gross time sales for radio advertising for the year 1935. This total amounted to $87,523,848, which was an increase of 20 percent over similar figures for the year 1934.[14] An estimate of the place of radio advertising in the general scheme of advertising in the United States may be gained from the following table:[11]

Advertising revenue

Advertising medium:	*Gross time and space sales for 1935*
Radio broadcasting	$87,523,848
National magazines[15]	123,093,289
National farm papers[15]	5,565,059
Newspapers[16]	517,513,000
Total	733,695,196

Broadcasting accounts for 12 percent of the above total.

Broadcasting is today an integral part of the everyday life of most people in the United States. It brings to the fireside finer entertainment than has heretofore been available to the average individual. This entertainment includes comedy, drama, popular music, and concert music. The gaining interest in classical musical programs is evidenced by the hearty response to the Sunday evening classical hours. Sports

[11] R. H. Langley, Review of Radio Broadcast Reception in 1935, Proceedings of the Institute of Radio Engineers, vol. 24, pp. 376–384, March 1936.

[12] Estimate of Number of Families Owning Radio Sets in the United States, January 1936, National Association of Broadcasters.

[13] Estimate of the Radio Manufacturers Association.

[14] Broadcast Advertising in 1935, National Association of Broadcasters Reports, vol. 4, no. 8, Feb. 7, 1935.

[15] Publishers' Information Bureau.

[16] Estimated.

have an important place on the program schedules of most stations, particularly during the baseball and football seasons.

An important function of broadcasting is, however, the conveying of direct information to the listener. This includes news broadcasts, weather reports, and storm warnings which are of major importance in certain sections, and market and livestock quotations which are an aid to those interested. Broadcasts by public health authorities have rendered notable assistance in preventing the spread of disease in times of crises such as that caused by the recent widespread floods in the eastern part of the United States. A notable service which may be classified as direct information is the discussion of current topics by prominent individuals in the fields of government, economics, and sociology which helps to acquaint the average individual with the numerous problems incident to modern civilization and assists him in arriving at better conclusions relative thereto. In this respect it has the effect of clarifying the thought of people on current topics and speeding their decisions in national problems. It is possible today to present to a nation within a few minutes through the medium of broadcasting information and discussions which would have been utterly impossible 15 years ago. This fact has a very striking effect upon the mobility of thought and opinion.

The radio with its increasingly permanent place in the home has a unifying effect within that home and it is thought by many that it may be responsible, to some extent, for counteracting the effect upon American home life which has been produced by the automobile.

Broadcasting, with its direct personal appeal, its easy and ingratiating entrance into the home, is in short the most effective and can be the most formidable means of mass communication which man has yet had the privilege of using.

An accurate estimate of the effect of the growth of broadcasting on related industries is difficult as it has affected many industries. It has provided a new field for many already established electrical manufacturers and for the establishment of other manufacturing industries for the production of radio transmitters, receivers, tubes, and associated equipment. Broadcasting has produced a new group of retail organizations which employ salesmen and technicians for the purpose of selling and servicing receivers. There are, in addition, many independent technicians who gain a livelihood through the servicing of receivers. Broadcasting has provided a new field of employment in the operation of the physical equipment and the preparation and presentation of programs for broadcast stations.

As the intensive growth of broadcasting has coincided with the growth of sound movies, it is difficult to evaluate separately its effects. Many of the musical activities which were previously confined to the concert hall have been transferred to the motion picture and radio studios. This has helped to make tremendously popular outstanding members of the musical world. It has raised the taste of the public in musical performers and in so doing adversely affected the small itinerant musical organizations which were known 15 to 20 years ago. In spite of this and the decrease in demand for musical individuals and organizations, since the advent of broadcasting and sound pictures, it is believed that there is an increased interest in the production and enjoyment of music by the amateur musician and music lover.

After considering recent trends and developments and studying inventions and laboratory improvements in existing equipment, a reasonably accurate forecast can be made of the trend of development in the broadcast industry for the next few years.

Improvement Trends.—One certain line of improvement will be directed toward the production of high-fidelity receivers at lower cost. Further steps will be made in adapting variable selectivity to receivers to provide for high-quality reception where signals are strong and interference not severe. This change in selectivity with the strength of the received signal strength will eventually be accomplished by automatic means within the receiver itself. There is at present in the laboratory stage a device which provides for semiautomatic tuning of the receiver. This device is not wholly automatic but when the receiver is tuned to the approximate frequency of a desired station the device accomplishes the fine tuning adjustments necessary for high-quality reception. The adoption of this device will aid materially in the production of remote control receivers. Eventually, it is expected that receivers may be designed which are wholly or partially "push button" operated, the selection of any desired station being accomplished by merely pressing the proper button.

Increasing attention has been given recently to development of receiving antennas which discriminate against electric interference and reduce the effects of atmospheric interference, thus enabling satisfactory reception of programs in locations where noise has heretofore made such reception impossible. Antennas of this type will receive an increasing amount of attention within the near future and it is probable that within a short time most receivers will be sold complete with a properly designed antenna system.

As previously stated, broadcasting was made possible through the invention of the vacuum tube. Modern broadcast receivers make use of vacuum tubes

which have been modified from the original design only through the addition of elements and their rearrangement. The recent development of a tube known as the "electron multiplier" may eventually supplant the present-day vacuum tube in broadcast receivers.[17]

Taken as a whole, the present-day broadcast receiver is a very satisfactory instrument which has attained a fairly high degree of perfection. Major changes in its construction and mode of operation are not anticipated. Changes when made will be more of the order of refinements than radical improvements.

The conventional broadcast band has heretofore occupied the portion of the radio spectrum between 550 and 1,500 kilocycles. Recent amendment of the rules and regulations of the Federal Communications Commission extended this band to include in addition those frequencies between 1,500 and 1,600 kilocycles. At present broadcast stations will only be assigned to three additional frequencies, namely 1,530, 1,550, and 1,570 kilocycles. These stations will be known as special broadcast stations; they will be limited to a power output of 1 kilowatt and licensed specifically for the purpose of conducting experiments or investigations which will lead to better quality of transmission, increased coverage through study of antenna design, and studies of public acceptance of high fidelity programs. Eventually, these frequencies may be made available for the use of conventional broadcast stations with certain requirements as to quality of transmissions and methods of operation.

Recent use of directional antennas for the purpose of limiting the amount of energy transmitted in any direction in order to protect other stations on the same or adjacent frequencies from undue interference or to enable a station to better serve a city or other populous area from a given location has produced gratifying results. The use of directional antennas on some of the frequencies will allow the placing of stations within areas where present broadcast service is inadequate without increasing interference to the reception of other stations operating on the same frequencies.

It is expected that among other improvements in transmission will be the use of greater power to provide a more favorable signal to noise ratio. The records of the Commission indicate that approximately 23 percent of the area of the United States, in which 64 percent of the total population resides, receives primary service from some broadcast station. This leaves approximately 36 percent of the population dependent upon secondary service. Primary service is that service throughout a continuous area from a broadcast transmitter where an adequate signal is laid down and no interference is experienced from other broadcast stations and no objectionable fading is found. Secondary service is considered as that service rendered outside the primary service area by signals, which may, on occasion, be subject to severe fading, atmospheric interference, etc. Increases in power when coupled with properly designed antenna systems greatly extend the primary service areas and increase the percentage of the time in which satisfactory service is obtained in the secondary service areas.

Recent studies of the propagation characteristics of radio waves indicate the desirability of using certain of the very high frequencies to secure limited local coverage for certain services. The transmission characteristics of the frequencies above approximately 40,000 kilocycles are such that satisfactory transmission is possible over a path which extends to the visible horizon. This is, of course, a function of the height of the transmitting and receiving antennas. This is a very desirable characteristic in frequencies for use in a service designed for local coverage only, as similar stations may be assigned to the same frequency at not too distant points without danger of interference. It has also been found that atmospheric interference (static) is much less severe on the very high frequencies. At present noises generated within the receiver at these frequencies are the important factors in limiting their usefulness. Receiver noises can, however, be reduced or eliminated through the development of new tubes and receiving equipment specially adapted for very high frequencies, whereas the reduction of atmospheric interference is a much more difficult problem. In addition there is the serious problem of man-made static such as industrial interference and interference caused by automobile ignition systems. It will be necessary to reduce this type of interference materially by improvements in the design of the automobile and other apparatus used as these frequencies come into greater service. There are some indications that the use of frequency modulation in the transmitter may overcome some of these difficulties. However, this will result in the need for specially designed receivers.

A phase of broadcasting which has widespread effect and is potentially an important factor in the creation and continuation of international good will is international broadcasting. Many of these stations broadcast musical programs, news bulletins, talks, etc., in languages other than the native language for the reception of foreign listeners on frequencies between 6,000 and 25,000 kilocycles. Needless to say, news digests, speeches, etc., which are colored to present a pleasing picture of the Government or other organ-

[17] This is a development carried on independently by Philo T. Farnsworth of Philadelphia of the Farnsworth Television Labs., Philadelphia, Pa., and V. Zworykin of the R. C. A. Mfg. Co., Camden, N. J.

ization broadcasting, will have some effect upon the opinions of listeners in foreign countries.

An increasing amount of effort is being expended in perfecting the mechanism of rebroadcasting, and frequently European programs are presented to American listeners with little impairment of quality due to the long distance over which they have traveled. The reception of programs direct from foreign broadcast stations and the rebroadcasting by United States stations of similar programs are important factors in fostering international brotherhood and good will, and through the development of better receiving equipment, increases in transmitter power and the use of directional antennas, it will be possible to continually improve the quality of this reception.

Broadcasting—Visual

There are two types of visual broadcast transmission which have great potentialities for service to the public; they are television and facsimile. Television has received a great deal of public attention, and the industrial research organizations, interested in the development of the electronic arts in this country, have spent tremendous sums of money in its study. This intensive research and development continues at the present time. Facsimile transmission, though not so well known, will have a marked effect upon the economic and social life of the country. This service is the broadcasting to the general public of signals which, when received on proper equipment, will produce printed matter and photographs much after the fashion of a modern newspaper.

The transmission of television images through the medium of wire or radio circuits has been an accomplished fact for at least 10 years. The first pictures were crude, the reproduction imperfect when compared with the modern motion picture and it has been felt by the industries that no system of television would be commercially feasible or receive any measure of public acceptance which could not transmit pictures of sufficient size to be readily usable in the home and of sufficient definition to compare favorably with the present motion picture. Research has centered around these two important factors.

The first systems made use of mechanical means of picking up and reproducing television pictures. What appeared to be a limitation to this means of pickup and reproduction was soon found and, while mechanical methods have not been abandoned, attention was turned to wholly electrical systems. Recent developments in the United States and abroad indicate that a fairly satisfactory picture, approximately 6 to 8 inches square, can now be transmitted by wholly electrical systems, making use of the very high frequencies previously mentioned as a transmission medium.

The system of pickup, transmission, reception, and reproduction required for television is necessarily complex. There are many different systems and many phases of the subject being studied by the various laboratories of the world. It is desirable that before any system of transmission be standardized for use in a country that the organization doing the standardizing, whether it be commercial or governmental, be satisfied that the system under consideration is the best available, that it is adaptable to continual improvement without rendering existing equipment obsolete and that all organizations wishing to transmit television signals will employ the standard system. Television will be a reality in the United States when it appears that a system has been evolved which meets these requirements and that there is a sufficient public interest and support to warrant the establishment of stations to broadcast television programs. One of the limitations which exists today in providing a Nationwide broadcasting service in the United States is the lack of available channels to accommodate television because each such station requires a very large portion of the radio spectrum; for example, 600 times that required by the ordinary aural broadcasting station.

Another limitation lies in the apparent inefficacy of the ultra high frequencies (where space can more easily be provided) for long-distance transmission and hence, there is some grave doubt as to whether television of high quality can be provided for rural areas in this country at a reasonable cost.

There is also some doubt as to whether the low frequencies which are already being used by existing services other than television will be suitable for rendering adequate television service to rural areas even though it be television of low definition. In any event, if rural areas were to be given low definition television and urban areas high definition television, it is certain there would exist economic and other problems in the production of two types of receivers and a certain amount of discrimination. Thus it appears necessary to concentrate television development or means which will enable the occupancy of smaller space in the ether, cheaper costs and methods enabling the standardization of transmission for both urban and rural areas.

The British Broadcasting Corporation is at present equipping studios and installing transmitting equipment in a wing of the old Alexandria Palace in London and it is anticipated that service will be commenced in the summer or fall of 1936 with two stations, each operating a total of 2 or 3 hours per day, one station using high definition electrical system of transmission and the other employing a mechanical system. It is expected that eventually the station employing the mechanical system will be converted to the use of the electrical system. The British Broadcasting Corpora-

tion anticipates an expenditure of approximately $900,000 for the development of this service during 1936. A committee of the House of Commons which investigated and studied the potential use of television in England recommended that before any system of transmission and reception is standardized the postmaster general and the board of governors of the British Broadcasting Corporation require the industries which have been responsible for the development of the various systems to agree upon a standardized system and form a patent pool whereby all interested members of the industry could manufacture and sell equipment under patents owned by other members.[18] [19]

The development of receivers for television has progressed to the point where it is stated by several manufacturers that, should a system of transmission and reception be standardized and public acceptance of television warrant quantity production of receivers, they could be marketed at a cost comparable with that of the home refrigerator. Such a receiver would include provision for the reception of the sound associated with the television program.

The transmission and reception of facsimile may be adapted to present-day radio receivers and there are available at the present time facsimile recorders which, when connected to the ordinary broadcast receiver and actuated by proper signals, will print a newspaper complete with pictures right in the home, though probably on a limited scale.

Who is there today who can predict with any degree of accuracy the effect on our home life and our business life of this new communication facility? It is possible today to sit in one's home and listen to voice and music from the far corners of the earth. In the future, this aural intelligence may be supplemented by another appeal to the senses; namely, the ability actually to see what is going on at some remote point, as well as to hear it. Recent tests in this country and abroad have demonstrated this possibility to be entirely feasible, and it is only a matter of refinement in development, reduction in costs, and providing and organizing adequate facilities to extend the available service from a few miles to many thousands of miles.

Color television is already a laboratory accomplishment. It, too, may become practical before long. Developments have already been started in three-dimensional sight and sound and, if we consider past progress in this field, is it too much to expect that a future generation of Americans will be able to sit at their firesides and see reproduced before them in actual colors and in three dimensions, both visually and acoustically, scenes which are being instantaneously transmitted from the interior of some forest, accompanied with all the fragrant odors of nature, and eventually the addition of a vicarious, tactual sensation?

Multiple Address—Telegraph and Printer

One of the most striking things to the average visitor in the New York financial district is the great number of so-called stock tickers. These, which are in reality printing telegraph machines, are to be found in the office of every up-to-date stock broker, bank, bond house, commercial investment company, and large business house, not only in Wall Street, but throughout the country. Their function is to maintain an automatic visible record, current stock quotations, and financial news wherever needed, and without the necessity of intermediate manual or code sending. They provide mass communication for a certain class of the public.

The next important step in the development of this mass communication was taken by one of the present communication companies several years ago with the introduction of the multiple-address printer. By means of this printer it will be possible for large and small newspapers throughout the country to enjoy a quick record news service fed from the nearest zone center. The plan envisaged approximately five centers appropriately distributed from a geographical standpoint throughout the country so far as to serve with a fair amount of power reception points located throughout these zones.

The next development came with the establishment by another of the press communication companies of multiple-address radiotelegraph service intended primarily to feed news rapidly and accurately to the 600-odd broadcasting stations throughout the United States. The news is transmitted at manual speeds ranging from 30 to 40 words a minute from strategically located transmitting stations and is received directly by capable telegraph operators at each of the broadcasting stations subscribing to the service. The service itself is operated by a new press collecting agency rivaling the old accepted newspaper press service.

If we can consider that these multiple-address or mass communication services will grow, we can look forward to the day when other special classes of the public, such as the police services, the aviation services, and the meteorological services, will have similar apparatus installed for the quick transmission and reception of similar types of messages. For example, a recent applicant for a mass communication service

[18] Report of the broadcasting committee, 1935, presented by the postmaster general to Parliament by command of His Majesty, February 1936.

[19] Report of the television committee, presented by the postmaster general to Parliament by command of His Majesty, January 1935.

of this type described what would be known as the doctors' call service. Under this plan, any physician making his daily rounds in his car could be called from a central office and knowing of the call in his car, he could immediately reply by going to the nearest telephone.

An amplification of this service would be the use of a small mobile printing apparatus in the car, whereby the message would be automatically recorded even while he was out of the car during a visit to a patient.

Other Technical Developments in Communications

Developments and improvements within the various communication services are of interest and are discussed here briefly. Mention will be made of only a few of those believed of fundamental importance to all radio services, all wire services, or both.

A quartz crystal plate, called the "AT Cut", has been produced with such a low temperature coefficient that for most practical purposes the costly and cumbersome temperature regulating system, which in some services is a barrier to the use of precise control of the frequency of emission, is unnecessary.

Considerable progress has been made in the application of wide-band transmission both in balanced wire circuits and in coaxial lines. By means of a cable containing two coaxial lines consisting physically of only two conducting pairs it is now possible to transmit simultaneous telephone messages in both directions numbering in the hundreds, simultaneous two-way telegraph messages, numbering in the thousands, and two-way television signals, requiring frequency bands of 1,000,000 cycles or more, heretofore impossible on wire or cable circuits.

This development has been made possible by three others which have universal application in both wire and radio circuits.

One is the quartz crystal filter by means of which the telephone channels, approximately 4,000 cycles in width, and the telegraph channels, approximately 200 cycles in width, may be isolated one from the other as effectively in the higher frequency ranges as has heretofore been possible, utilizing electrical elements only, in the lower frequency ranges.

Another is the negative feedback amplifier with improved stability of gain with changing amplification factor, plate voltage and variations in the amplitude of input signals, together with reduced distortion due to modulation products, thereby permitting greater volume ranges of signal to be transmitted, while at the same time in push-pull arrangements, obviating the necessity of employing vacuum tubes of matched characteristics and therefore facilitating unattended operation.

Still another is the application of double and triple modulation and demodulation systems, by means of which the frequency bands of the signals to be simultaneously transmitted, may be translated by desired uniform amounts, and placed side by side in the frequency spectrum for transmission, later to be retranslated to their original place in the frequency scale prior to reception.

The use of these new devices in combination, together with automatic transmission regulators to hold the impedances of circuit elements constant within set limits, regardless of temperature variations, promises to make the use of wide band transmission systems a practicality with accompanying benefits to the public in increased communication facilities.

A new vacuum tube circuit has been developed which automatically contracts the volume range of signals to be transmitted and transmits the signals over a wire line or through the modulating system of a transmitter in their contracted state, while a similar device at the receiving end of the wire or radio circuit automatically expands the volume range to its original volume or to any desired fraction thereof.

This development is of importance in improving communication on all wire and radio circuits where the signal to noise ratio is the limiting factor in obtaining satisfactory service.

Contributions to the theory of the operation of vacuum tubes at ultra-high frequencies, combined with experimental studies, have resulted in the production in the laboratories of tubes of new construction, the operating range of negative grid oscillators being increased thereby to 300,000 kilocycles and above with appreciable power output.

One such tube described in the literature furnishes a power of 6 watts on 500,000 kilocycles with an efficiency of 19 percent.

It is probable that by the time it becomes possible to allocate the ultra-high frequencies for commercial use the range for which apparatus will be available will have been considerably increased by the production of such tubes on a commercial basis.

A new type tube for which long life and great amplifying powers are claimed has been demonstrated. This tube, which may be used both as an oscillator or amplifier, has been called the Electron Multiplier, or Multipactor. It employs cold cathodes and a centrally located anode, utilizing secondary emission of electrons from the cathodes for its operation.

The trend toward the use of higher power by radio stations and the extensions of the applications of radio have resulted in research for the improvement of modi-

ulating systems better adapted to specific types of radio service.

The greater necessity for economy in the operation of high power stations has initiated analytical studies, which have resulted in disclosures of practical and simple methods of calculating or determining by graphical analysis the fundamental and harmonic output currents for various values of applied grid voltage as well as the optimum plate impedance, in class B and class C amplifiers, from the tube constants, the operating voltages, and the limiting output power.

These extensions to vacuum tube theory which include the curvature of the tube characteristic and the discontinuity of plate current flow, together with graphical methods by means of which output, efficiency, and grid excitation may be readily determined have aided materially in increasing the efficiency of operation and the design of radio transmitters.

New and improved instruments have been designed and made available by means of which operators of radio stations maintain better control of transmission, through more accurate measurements of normal characteristics, such as percentage of modulation and frequency bands of emission, as well as abnormal ones such as spurious emissions and objectionable distortion.

Interest in the development of ultrahigh frequency circuits will no doubt bring forth new technique in the design of precise measuring equipment since equipment and methods normally used on the lower frequencies are reported as inadequate by the laboratories. This being the case, the laboratories will in time produce new equipment of greater accuracy, the beneficial results of which will no doubt be reflected to the lower frequencies with consequent improvement in apparatus and methods of operation.

Much work has been done both theoretically and experimentally in the improvement of antennas for all radio services, particularly with respect to reduction of sky wave and fading in the intermediate frequencies, the reduction of signal to noise ratio and fading due to phase interference on the high frequencies, and the advantages or disadvantages of different types of polarization.

Knowledge obtained experimentally of the direction of arrival of high frequency waves has indicated the possibility of minimizing the effects of fading through the use of antennas with sharply directive patterns to discriminate against reception from all but one of the interfering paths.

As in other phases of radio work, activities in the ultrahigh frequencies have also influenced the trend of antenna design because of the ease with which verification of the results of theoretical work may be obtained with antenna structures of small dimensions.

Many research workers of both the United States and foreign countries have made valuable contributions on the subject of wave propagation, of vital interest to those engaged in radio communication in all services, including those utilizing the lower frequencies by means of direct or ground waves, those operating on the higher frequencies returned to the earth via the ionosphere, and those contemplating the use of the ultrahigh frequencies.

Some research workers have reported a variation of transmission on the ultrahigh frequencies, below the line of sight, believed due to refraction and variations in the moisture content of the atmosphere. If a correlation of weather conditions and such transmissions may be obtained, a new field of usefulness for radio may be realized in connection with weather forecasting.

A large amount of valuable data was obtained during the year 1935 as a result of studies of the structure of the ionosphere. Recordings of the virtual heights of the various conducting layers and the variation of their critical frequencies throughout the seasons have been continued at different locations throughout the world. The knowledge of the variations in ionic density of the upper regions of the atmosphere and its effect on radio transmission thus obtained will be of inestimable value in improving world-wide radio communication.

As the signal to noise ratios obtainable on various frequencies in long distance radio communication circuits are also limiting factors in the attainment of satisfactory service, of equal import are the results of some theoretical and experimental studies that have been made on the frequency distribution of atmospheric noise.

The ultrahigh frequency developments have also revived the interest in the possibilities of frequency or phase modulated signals for communication in certain classes of service.

Because of the fact that in electron oscillators, which may be used for communication on frequencies above 700,000 or 1,000,000 kilocycles, there is considerable frequency shift with changes in operating plate voltage, it has appeared that frequency or phase modulation rather than amplitude modulation may be more advantageous in these regions of the spectrum. As a result, some important theoretical and experimental studies have been made and the results published on this subject.

In addition, a radio communication system, employing frequency modulation, for operation on the ultrahigh frequencies has been disclosed, which promises other important advantages, namely, reduction of tube noise to a point where it is less than 1 percent

of the energy of the disturbances in an amplitude modulated system of like power. If such systems are found to be satisfactory under practical operating conditions, the ranges over which communication may be obtained in ultrahigh frequency circuits will be materially increased, for the tube noise rather than atmospherics or man-made electrical interference is the limiting factor in determining the minimum signals receivable on these frequencies.

The Radio Spectrum

In a brief review of the spectrum's history, we have considered its expansion during four periods of its life within which its development has obviously depended, not only on the advances in the radio art within these respective periods, but also upon the economic conditions within them which have made its use profitable to the radio-communication industry.

The spectrum, throughout its life, has depended upon two main factors for its growth: one a technical factor and the other a commercial one.

Accepting conditions as they are and forgetting for the moment the possibilities of technical improvement in methods of operation, we find the spectrum within the regions between 10 and 23,000 kilocycles being used very nearly to full capacity. Practically all of the available frequencies within this range have been allocated and are at the present time being used by one or another of the 26 authorized radio services, or by the radio service of some foreign country.

It has been very difficult within the past 5 years to find sufficient frequency space for our new important, rapidly growing radio services, such as aviation and police.

Leaving out of consideration for the moment the work of our scientists, radio engineers, and research workers, who have been responsible for those advances in the radio art which have made the spectrum's expansion possible, let us consider the present status of the spectrum, particularly with respect to its possibilities for increased commercial use and its capacity thereby for rendering additional service to us all in the realms of communication.

Viewed in this light, the expansion of the spectrum during the first period of its life, before mentioned, was due to the commercial use made of it by those in the maritime industries.

Its growth during the second period was the result of the use made of it by the broadcasting industry and by those looking forward to the development of our radiotelephone services.

Those interested in the development of international communications were responsible for the growth during the third period, while its expansion—soon to come—into the ultrahigh frequencies—will have been due to those during the fourth period who have been willing to spend their time and effort in studies leading to its use in commercial service. Among this group the amateurs are outstanding.

When we consider the capacity of the spectrum for service, we must consider it both from the technical and the economical standpoint. Even in those regions in which we consider it most congested, it is not being used to full capacity were we to eliminate economical considerations entirely.

The minimum channel widths which may be assigned for communication in any service depend upon the type of emission, the frequency stability of the transmitters, and the selectivity of the receivers, in the communication circuits, which station owners can afford to use, depending upon the degree of public support the service receives, and in turn upon the economic condition of the times. The narrower the channels which may be assigned, the greater are the number in the spectrum available for assignment and the greater the capacity of the spectrum for service becomes.

In the field of international communications, additional factors must be considered, for the standards of operation which may be obtained depend on the equipment at both ends of the circuit. International agreements as to standards of operation, are, therefore, essential before definite standards as to the width of assignable channels may be decided upon.

All applicants for radio facilities requesting frequencies within this range for the use of new services have been required to meet the test of "public interest, convenience, and necessity" to the point where the withdrawal of frequencies from other services has appeared to be justified.

In addition, if the new services proposed are of such character as to necessitate the use of frequencies within the bands subject to the provisions of international treaties or regional agreements with neighboring nations, satisfactory showing must be made that the frequencies requested may be used without causing interference to the radio services of any foreign country having prior rights in the use of the frequency and without violating in any way the international commitments of our Government.

In the regions of the spectrum between 23,000-30,000 kilocycles, no congestion exists, but it so happens that these frequencies are in the border land between those which are advantageous for short distance communication and those advantageous for long distance communication. The reason for lack of congestion so far, within this region, has been lack of demand for their use.

The greatest opportunity for commercial development of the radio spectrum at the present time is without doubt within the range 30,000-100,000 kilocycles or possibly on up to 500,000 kilocycles, depending upon the limiting very high frequencies found to be usable under practical operating conditions, utilizing vacuum tube oscillators in conventional circuits.

It has always been the Government's policy to put new, hitherto unused, frequencies to work as soon as a satisfactory showing has been made that the frequencies were ready to go to work.

As a result of this policy of encouraging all experimental work in this field, many useful data in the solution of the allocation problem have been obtained within the last 4 years, and beyond doubt the time is not far distant when the radio spectrum, as we have arbitrarily defined it, will be further expanded to include the range of frequencies above mentioned.

When this is accomplished, there are regions beyond in the realms of the electronic oscillators, and we may be assured that the research workers in the laboratories will be ready with the equipment by the time those busy in the commercial fields of radio communication are prepared to use it.

Conclusion

Perhaps no industry in the world has had such a rapid growth and such remarkable development as has taken place in communications. We must content ourselves with a study of past progress in this field, and by drawing certain imaginary graphs of past progress, attempt to project them into the future in such a way that certain trends of themselves become apparent.

Even such an elementary attempt becomes difficult when we consider the tremendous implications which underlie the balance between engineering development and the social and economic trends in communication. For example, in the telegraph industry, does the future hold in store a Government monopoly, as is the case in most European countries, a commercial monopoly as many of the leaders in the commercial communications field desire, or controlled competition which would have both some of the advantages and some of the disadvantages of each of the other systems?

In the engineering field, it is quite apparent that development is taking place very rapidly.

One important trend is the great increase in the use of communications for purposes which 10 years ago had not been even considered. For example, the tremendous growth in two-way police systems; the dependence of the aviation industry on radio as a vital part of that branch of transportation; the growth in the use of radio for such miscellaneous services as geophysical exploration parties, coastal harbor radiotelephone service to fleets of fishing vessels and tugboats, harbor communication to fireboats and the great number of incidental services using general experimental frequencies for scientific development.

Probably the most significant trend, however, is the relative imminence of television. Since 1929, television as a scientific tool has been in a rapid process of development in many large and small laboratories in this country. From time to time predictions have been made that "it is just around the corner", and the particular corner usually referred to was an engineering one. A number of laboratories in this country have now developed the technical phases of this art to the point where it can safely be said that, although many, many technical problems remain to be solved, it is, nevertheless, possible to transmit over a local area of 10 to 20 miles radius fairly good pictures having the clarity and details of the average home moving picture.

The next corner to be turned, however, is an economic rather than an engineering one, and it can be stated briefly in one short question "Who is to pay for television?" Will the public accept a television service based upon a continuance of the present system of commercial aural broadcasting and its extension into television? Will a "looker-in" be willing to sit in a darkened living-room at home intently peering into the screen of his television receiver?

It is believed that the greatest service which communications can do in the future will be to provide extensions into the hitherto remote and inaccessible places whereby people who formerly had no means of communication can be connected with the communication arteries of the world. Tremendous progress has been made during the last decade in this direction and, undoubtedly, tremendous progress will take place in the future. The other great forward step in world civilization which can be made is in the effective use of communications, both telegraph and telephone by wire, but more especially by radio, in the development of understanding, mutual respect and tolerance among the nations of the world. Much has been done along these lines in the past and a great deal more is expected in the future.

Much of this service will be accomplished by printer, by facsimile transmission, and by long distance vision. There are thousands of inventions which have been made in the past and it is confidently expected that a similar number will be developed in the future in the solution of the age-old problem of mankind—Communication.

COMMUNICATION BY PRINTING AND PHOTOGRAPHY[20]

Introduction

The social implications of printing when considered from the viewpoint of its subject matter could not be adequately treated even in many volumes. The rapidity with which changes are taking place in the adaptations of the basic principles of the art of printing to meet modern demands for greater speed and increased production makes it difficult to predict the precise course it may follow in the next few decades. A renaissance of the long-established and once outmoded processes of reproduction in forms modified to meet a new set of conditions appears to be taking place. Of such a nature is the development of rotogravure printing, familiar in the Sunday supplement sections of our newspapers. This is an adaptation of the older process of photogravure to the present requirements of production and the use of less expensive papers. Another illustration of this application of a long-established process to meet modern conditions is planographic or so-called offset printing which was the outgrowth of stone lithography practiced in the infancy of the printing press. This process is at present in keen competition with the established forms of typographic printing and may, when coupled with improved photographic methods, the limitations of which are rapidly being removed, prove to be one of the principal methods of printing for the future. The lure which this process extends to the printer consists in its low cost and the simplicity of its operation together with the wide variety of papers upon which the printing can be done. Developments in photocomposition of a more accurate character, such as the Uhertype machine promises, and improvements in sensitivity of the process photographic films now on the market are contributing to speed the progress of this method. An ultimate goal of achievement may be the almost complete elimination of the use of metals for type forms by composing the printed matter directly upon photographic films to be printed upon the planographic metallic press plates.

It may well be said that each of the major processes now employed—the letterpress, the offset, and the rotogravure—has its place in the world of printing and their individual strong points will cause them for a long time in the future to function together harmoniously in accordance with their peculiar virtues. For different classes of printing each of them will be indispensable. One of the most attractively printed modern magazines employs all three of these processes together in each issue of its publication with most satisfactory effectiveness. Several magazines use at least two methods simultaneously. Therefore, it is not to be feared that any of these processes will soon suffer extinction in a struggle for the survival of the fittest.

Chemical and physical research are also producing rapid development of the agencies upon which the functions of printing depend. Metals, inks, and papers have all felt the touch of science and profited by the removal of many of the uncertainties and variables of control in their manufacture. Although the improved quality of these products fundamental to good printing have not, because of this careful and systematic study given to their manufacture, solved all of the problems of the printer, they are assuredly smoothing his pathway somewhat toward better progress. The high degree of mechanical and chemical precision even now attainable opens a new era in high quality of printing which is not incompatible with the strenuous demands made upon it for rapid production. The general principle underlying this advancement lies in that accuracy of procedure which determines and assures quality defined by precisely measured characteristics.

The present trends in printing are therefore toward improvement in quality and increase in quantity of the objects produced.

It may be interesting here briefly to trace the historical pathway which the art of printing has taken since its introduction into the New World from the Eastern World (China) and Europe, where the development from its rudimental forms required many centuries, and to indicate by contrast with its phenomenal development during the present generation, what trends it may take in those generations of the world of printing immediately to follow.

In 1620, the Pilgrim fathers landed on Plymouth Rock. In 1638, the first printing press arrived in Massachusetts. In Governor Winthrop's "Journal" is found this entry:

"1639, No. 1. A printing house was begun at Cambridge by one, Daye, at the charge of Mr. Glover, who died on seas hitherward."

We thus learn that in March 1639, the first New England printing plant started operation. Only three years earlier than this event Harvard College had been organized. This establishment of a great educational institution in the midst of the Pilgrim colony was fittingly accompanied by the pilgrimage of the printing press from the Old World where culture had been reawakened through its influence. In 1640 there appeared the first definite publication from the press of Stephen Daye under the title of "The Whole Booke of Psalmes, Faithfully Translated into English metre

[20] By A. E. Giegengack, Public Printer.

* * * Imprinted 1640." This was the first book printed in English in America.

From this beginning the art spread rapidly, and during all periods of development and colonization in the Western Hemisphere printing both influenced and was influenced by the social customs of the time. The sociological effect of printing as a means of increasing the scope of human communication would be difficult to estimate.

It must be borne in mind that the greatest development in this field, as in other fields of invention and mechanical progress, has occurred within the present generation, and principally within the last quarter of a century. It can now truly be said "Of making many books there is no end." With the increasing speed of all human activities has come a demand for rapid and voluminous printing. From the time of the introduction of the hand printing press in New England and the establishment of the first American printing house by Stephen Daye in 1639, typography grew in proportions relative to the growth of the new nation.

The influence of printing upon the moral and social development of the New World must be associated with the subject matter of the printing in any given period. However, an interaction of influences also occurs, and the printed matter of a particular period tends both to form and to reflect the manners and customs of the people of that period.

It is interesting to trace certain of these interacting influences as reflected in the typography of progressive periods of American printing. In this country typographic styles appear to have been transformed about every 30 years. Since this period of time seems to constitute the active influence of a given generation, such changes have occurred not only in typography but also in styles of dress, and in modes of living and communication.

The hand press as a method of printing had been in use since the days of Gutenberg, nearly four hundred years, with but little or no modification of its form when Samuel Rust, about 1829, invented the toggle-joint Washington hand press and Isaac Adams, in 1830, produced his power platen press that did the work of 10 hand presses. The first issue of the New York Sun of 1833 was printed on a hand press. In 1835 Harper and Brothers still printed all of their books by means of hand presses.

In the 30-year period beginning with 1840 photography was in its infancy and had not been applied to printing. The telegraph had recently been invented and the age of discovery was being ushered in. Electrotyping was introduced into America in 1841 but was still undeveloped and rarely employed. From the time of the invention of formal printing, type was assembled by hand until a few years before 1840, when a typesetting machine was invented. A notable achievement in printing presses was Hoe's type-revolving press, the first machine, a four-feeder, having been used for the first time in 1846. This machine, which had the type faces fastened to a revolving cylinder by wedge-shaped column rules and other devices to keep the type in shape, was further developed until 10 feeders were required to operate it. This gave the first decided increase in newsprint production.

The printing of this period was in general somewhat somber as a study of the type faces and wood cuts used by all printers of the time indicates. There was a dominant black tone in the types and in illustrations, combined with a certain squareness and plainness of form that reflected a rugged and pioneering period.

The next period in American printing was coincident with the spirit of exultation and celebration from 1870 to 1900. The Nation which was a century old had come through a period of pioneering and exploration, and the people felt like celebrating. This desire for celebration found expression in the Philadelphia Centennial Exposition of 1876.

The stirrings of the popular imagination are reflected in the period's ornate style of printing in which floral designs and scrolls abounded both in books and on business cards. In this period schools were better organized and education was extended to include both art and music. The telephone, marking a new epoch in human communications, was invented by Alexander Graham Bell, and methods of more rapid interaction and transportation were everywhere becoming apparent.

The invention of machines for typesetting was born of the need for more rapid composition to meet the increased public demand for printing of all kinds. Hand compositors through typesetting contests had developed the ability to set 2,000 ems an hour, but even this did not suffice to meet these demands. It was in the latter part of this period that the Paige typesetting machine was built, in the promotion of which Samuel L. Clemens (Mark Twain) invested and lost a small fortune. This machine was so wonderful and intricate that it became a commercial impossibility. In the printing industry America did not lead in invention. Most of the progressive machinery of printing originated in Europe, although greater perfection and efficiency have been given to all of these devices by American inventors and promoters.

The 1900 period of printing (1900 to 1930) represented a change of thought. The Spanish War had just been victoriously fought. Land had been acquired in the Orient and the interests of the people were expanding to become more world-wide. There was an awakening in literary and art circles. Little pocket magazines

published in all parts of the country were popping up on the newsstands. Typographically, America was setting a new style of printing that will long be recognized as one of the most interesting and picturesque in the history of this art. About 1915 new type styles were introduced by such designers as Frederic W. Goudy, based on notable types of Italy and France of the earlier and more classical days of typography.

The World War was then in progress and rapid developments were being made in the fields of science and mechanical invention. Under the stimulus of this period scientific discovery and invention brought forth greater developments than were achieved during several previous centuries.

The increased speed of communication by radio, airplane, streamlined automobiles, and railway engines reflects the tempo of the times, and this lively spirit is also expressed in printing as in art, architecture, and other phases of human life.

Means and methods for pictorial illustration in almost bewildering multiplication have been or are being perfected. These involve the fundamental principles of the older processes of reproduction as well as modern offset photolithography and the more recently developed rotogravure intaglio printing.

Color is introducing a dominant note into picture printing, and excellent three-color and four-color prints are now being produced both by the rotogravure and offset processes. This has made possible the use of thinner and less expensive papers than those formerly demanded for the printing of three-color halftones by the older photoengraving processes.

It may be briefly said that printing has always been a powerful factor in the formation of social customs and in giving impulse to the development of human knowledge through its dissemination. While influencing the course of civilization it has also felt a reacting influence and has served as a mirror of whatever period marked its accomplishment. Together with radio and motion pictures at present, and television in the near future, it is one of the principal agencies for mass communication.

Technological Trends

Not even a vision could have revealed to the chemist, Perkin, in 1856 that a flood of brilliant color would sweep through the industrial world and burst over the dams of printing presses as it is doing today, as a result of his quest for a way to make quinine. He was greatly surprised when his chemical combinations of aniline and chromic acid resulted in the birth of mauve, the first of the aniline dyes and the progenitor of the dyestuffs industry.

From the lucky accident which thrilled Rubel when his feeder missed a sheet and, in the absence of the paper, made the impression upon the smooth rubber blanket and thence to the next sheet of paper sprang the offset printing process.

It would likewise tax the powers of a prophet in this generation to predict the results upon the generations to come of present-day developments in the realm of printing.

However, there are certain trends or tendencies toward change in the present industry of printing which are in themselves somewhat prophetic. New developments rapidly occurring through scientific research into the chemistry and physics of the already existing printing processes indicate very definite changes in the methods of printing of the future.

The three major types of printing—the relief or cameo, the planographic or offset, and the intaglio or gravure—have all felt the touch of scientific development and procedure.

The relief-printing copper half-tone plate is giving place to the offset half tone both in monochrome and color. The tendency of the older relief process of printing to take the direction of offset lithography and rotogravure is due to the fact that in the latter processes of printing rougher surfaced and less expensive paper stocks can be employed to obtain equally good effects. It is true that some pictorial detail is lost in the new processes, however, and for this reason, if for no other, the older type of photoengraving printing upon coated paper stocks will retain its well-earned laurels for certain types of pictorial reproduction.

Pictures speak a universal language understandable by even those of limited literacy. The Chinese have a proverb, "A picture is worth ten thousand words." Word pictures, in fact, could never be as effective in conveying collective impressions. The present development of picture printing, and especially color reproduction, has far outshone the rosiest dreams of the pioneers of the process. Its future employment as color illustration in the fields of art and advertising is assured.

In 1829 the Frenchman, Nicéphore Niépce, in his old age was writing the preface to a work in which he intended to record the results of 15 years of uninterrupted labors on the invention of photography, although he had not arrived at the conclusive results for which he had hoped and for which he had fought with great energy until health failed and despair overtook him. For the book he had in mind he wrote the following: "It is based on observation of light phenomena which have scarcely been noticed until now. It is the fruit of researches, extending over many years, for solving a very curious and interesting question, namely, to find in the emanations of a pencil of light an active force that can impress in an accurate and steadfast manner an image given by optical

means. I do not speak of impressing it with all its variations of color, but with every change of tone from black to white. In fact I think that whilst it may be possible to discover, by means of chemical combinations, some phosphorescent material which possesses the special property of retaining the colored rays of the prism, nevertheless it would be very difficult to obtain a print which would not change quickly."

"I am hopeful", said Mungo Ponton 10 years later, as he held the sheet of paper which he had made sensitive to light by dipping it into a solution of bichromate of potash and drying it—"I am hopeful that this method may be found of considerable utility in aiding the operations of the lithographer."

Today we are astounded to behold the amazing number of processes in which the active force vested "in the emanations of a pencil of light" is operating; how applied chemistry has achieved what Niépce doubted could ever be achieved in color photography of a permanent form; and the effect which the bichromates, that Ponton hoped would be of "considerable utility", have had upon printing. To these pioneers in the arts who blazed the trail for all generations of printers who have followed them belongs immortal praise.

Pictorial reproduction by graphic arts entirely depends upon the photographic methods of those early investigators. That "pencil of light" is still extending its rays into the future. The present trend in printing is to resort more and more to photographic means of reproduction, not only of pictures but also of type matter.

Modern Lithographic Printing

In increasing numbers, books and magazines are being printed by the offset lithographic process, which consists in printing the image from a metal plate to a rubber blanket and thence to the paper by means of the mutual repellent powers of water and inks. This printing image is placed upon the plane surface of the metal plate by means of a film of bichromated albumen exposed beneath a photographic negative until the albumen has become insoluble where affected by the light.

Lithography (literally "stone writing") was the parent of modern offset printing. In true lithographic printing, however, the images to be reproduced were placed directly by hand or by transfer media upon Bavarian sandstone with a greasy crayon or ink. The porous character of the sandstone surface permitted it to absorb water and to hold the ink. When the stone was moistened before printing, the nonprinting areas which had absorbed the water would therefore repel the ink, the ink being deposited only upon the greasy portions for printing. The printing surface was neither raised nor depressed and this fact gave to the process the name of "planographic printing" to distinguish it from the other two chief methods—relief or typographic and the intaglio process. Impressions were taken by placing the paper directly in contact with the stone.

Later Alois Senefelder, another pioneer of printing, paved the way to modern "offset" methods by substituting thin metal plates for the thick and cumbersome stones. These metal plates were grained or scratched by abrasives to produce a porous surface for the adsorption of water to function in the same manner as the lithographic stone. In the present form of offset lithography the thin metal plate, bearing the photographically reproduced printing image, is strapped to a cylinder over which water-dampening rollers and ink rollers successively pass, the water and ink adhering respectively to the nonprinting and the printing areas. This plate cylinder is synchronized to contact another cylinder to which a thin rubber blanket is strapped and to which the ink image is transferred, or "set off" from the metal plate. In turn this rubber blanket contacts an impression cylinder bearing the paper which receives the print.

Much scientific research has been devoted to this process within the past few years and it has rapidly progressed and been placed upon a commercially firm foundation. The scientific investigations of those industrial producers and machine manufacturers whose interest has been to promote the product, have added much to the possibility of this printing process successfully competing with the letterpress in the near future.

The recent introduction of the intaglio method of producing "deep-etch" offset printing plates is doing considerable to improve the quality of printing both of monochrome and color work. It is possible in the near future that the water-fountain and roller-dampener methods of moistening the printing plates to repel inks in nonprinting areas may be displaced by the "isolith" method. This consists in cooling the plate cylinder with refrigerants and blowing warm moist-laden air over its surface, upon which the moisture condenses and is adsorbed by the metal on the areas which repel the ink. This will lead to richer tone quality in this type of printing by avoiding the possibility of water emulsification of the inks and consequent loss of values which frequently occur when water-bearing rollers are used to dampen the entire plate surface.

Intaglio offset or "deep etch" has, like photogravure, been compared unfavorably with letterpress half tones in the matter of permitting the correction of tonal values of light and shade after the plate is made. In the case of offset, however, a process has been recently

developed for reducing by chemical treatment the dot sizes in the high lights or completely eliminating them in the negatives themselves before printing upon the metal plate. This corresponds in effectiveness to the re-etching of a copper half-tone plate for letterpress printing. Other inventions to achieve the same purpose, of introducing contrast into the prints, consist of specially formed half-tone screens or lens apertures or a rotation of the regular cross-lined screens during exposure of the negative, as practiced in the Bassani process of photoengraving.

The great improvements which are being made in the mechanism and the process of offset printing indicate that but one drawback prevents its more widespread introduction, namely speed of production. This lack of required speed has prevented the process from being more widely used for newsprint purposes. However, offset printing is tending to be more and more employed both for book work and magazine publication. Certain current moving-picture magazines are a witness to this fact.

The new web-fed offset presses which print from a continuous roll of paper may, upon achieving the desired speed, radically revolutionize printing in the newspaper world.

The offset process is being applied to an increasing extent to small-form printing and reproductions. Two machines, one originating in Germany called the Rotaprint and the other very similar one in this country called the Multilith, are extensively used for this kind of work. The present trend is for large offices and civic corporations to install Multilith machines to do their small-form printing and to replace the older mimeograph form of duplication with this more recent machine which produces a different quality of work. This process, of course, usually requires the use of a camera and involves the development of some skill in preparing a suitable negative and transferring the image to the metal printing plate. This also has had a tendency to curtail its more universal use.

In the field of photography connected with the offset printing process, improvement in the quality of photographic films has kept pace with the exacting demands. Orthochromatic films possessing greater speed factors are now making it possible to photograph discolored or yellowish copy with sufficient density of the image to obtain superior results in printing by the offset process.

A more recently invented process has succeeded in printing a continuous tone photographic negative directly upon the offset printing plate without a screen pattern. The result is an excellent gradation of tone values which can be controlled by manipulating the albumen image over the plate grain permitting the grain of the metal plate to show through in the lighter tones with an effectiveness similar to that of collotype printing. This is being applied to the reproduction of aerial photographs of land topography in map making, and may well be adapted in the very near future to obtaining more artistic results and greater detail in pictorial printing through reproduction by offset lithography. It may do much toward enabling this process to equal the quality of half-tone reproduction attained by the older processes of relief printing upon special smooth coated papers.

Photoengraving Methods

The camera has always been the indispensable friend of the printing press and its influence upon the technical processes of printing is destined to direct the future course of this industry.

With Gutenberg's contribution in the discovery of the use of movable types came the dawn of a new era of enlightenment and the dissemination of knowledge which has in our time become almost boundless in its many ramifications.

Like the scribes who preceded them, embellishing their texts with pictures and displaying marvelous skill and technique in book illumination, the early printers also saw the need for pictures and were forced to resort to the hand engraving of printing blocks as a means of accomplishing their ends. These were cut upon various materials, wood, metals, and stone and fulfilled their purpose as long as printing was done by hand.

With the advent of power-driven printing presses of greater and ever-increasing speed came the demand for a method of engraving to keep pace with printing. Photography saw the light of day shortly after the time of this mechanical speeding up of printing, and since it possessed the power faithfully to reprodnce whatever came within the range of its eye, the lens, the camera was adopted by the printing craft.

It has been truthfully said that man is "eye-minded." We receive our most sensitive emotional impressions and obtain the greatest measure of knowledge concerning the world in which we live through our sense of sight. The realization of this fact accounts for the present popularity of motion pictures, magazines, and tabloid newspapers. It accounts for modern advertising which depends upon pictures for its appeal and success. It permits the introduction of the fine arts into advertising.

The Scope of Advertising

The printing industry is rated as the sixth ranking industry in the United States. Attached to this industry and depending upon it are the printing supply trades, including builders of printing machinery, manufacturers of ink, type metal, and paper

and the myriad of incidental supplies which enter into the composition of printed matter. All of these will be stimulated by the ever-increasing volume of pictorial advertising and printing.

The value of emotional response to illustrations made by the photoengraving process is so well recognized today that enormous sums are paid for art work as an aid to advertising. This is done with the realization that engravers and printers can faithfully reproduce the works of great commercial artists. The growth of visual advertising has progressed in proportion to the development of the engraving and printing processes.

The social and economic influence which this art is bringing to the industries and to the world at large can hardly be overemphasized. In addition to serving as a blessing to advertising, photoengraving has helped to enrich the lives of countless thousands of people. Through photoengraving and the printing press, the art treasures of the world are being brought to the masses. Advancing hand in hand with color photography and color printing developments it is destined to have far-reaching influence. As the handmaiden of advertising it is illuminating the cold type which, no matter how beautiful the typography, cannot give the reader such a vivid visual impression of what the product looks like or how it works. The automotive industry in particular is keen to grasp this advantage. The motion-picture industry employs it in reproducing thousands of still pictures, some of which are taken from their current film strips, in the course of a year. Scores of talented artists are employed by motion-picture producers to give in practically every technique their conceptions of various aspects of photoplays and stars. Magazines and theater posters abound with illustrated advertisements of coming attractions. The railroads and water lines present through this means the lure of travel and vacation land. The imagination is scarcely capable of compassing the multifarious uses of the photoengraver's art.

Inventional developments which affect the operation, quality, and production of this work in the field of printing must necessarily have a far-flung effect upon the industrial developments of the future.

Much of present-day printing and picture making is concerned with some phase of advertising. Much art is here being employed, and through this channel inventions and improvements in products which affect the living conditions of the people are brought to their active attention.

Photoprint

In 1935, 58 percent of all the publication advertising in the United States was placed with the newspapers.

The character of department-store newsprint advertising has distinctly changed during the past 5 years. The area occupied by type matter has been reduced considerably in proportion to the size of the advertisement and the space utilized for better quality illustrations with the addition of hand lettering.

Consequently there has been developed a new style of advertising in newsprint circles, calling for new methods, both from the standpoint of economical production and better quality of reproduction.

In this type of photoengraving work in the advertising field, speed of production is of the greatest importance. Frequent delays occur when the advertiser requires, at the latest possible moment, changes to be made in the proofs submitted before publication. This request for changes sometimes is made several times before the advertiser approves the proofs. It has been the custom for photoengravers, after making suggested changes, to etch new metal plates from which corrected proofs are pulled. This is an expensive and time-consuming process when several revisions are made before the final acceptance of the cut for publication.

The process has been greatly shortened and improved by a method of treating the copy brought to light in 1936. This invention is known as the "photoprint system" which aims to stop, or at least to minimize, the great waste of time and money involved in making advertisers' revisions and the remaking of photoengravings on account of them.

The system consists essentially in making a positive photostat print on bromide photographic paper of the original drawing representing the basis of the illustration. Upon this photostat print whatever art work is necessary to improve its quality or to modify its appearance is made. Next the type matter to accompany the illustration is set up in register with the copy and a proof is pulled upon a thin sheet of cellophane which is then temporarily pasted down to the original photostat illustration with rubber cement. This composition is then submitted for approval as representing the final appearance of the printed article. If corrections or last minute alterations before publication are suggested they can easily be introduced upon new cellophane sheets and superimposed upon the copy until the final desired appearance is attained. When the alterations are completed the corrected proof is then regarded as the new copy which is photographed and reproduced in the form of an etched plate ready for the press. By this process it is possible to prepare advertisement cuts containing any combination of line work, fade-outs, half tones or Ben Day screens, and type display as a single engraving on one-piece metal.

The use of this invention should prove to be far reaching in its application to printing and photography, since refinements of the process may be included to make the method applicable to higher classes of reproduction than newsprint advertisements.

A similar method is already being employed in making drawings on sheets of cellophane which are superimposed in preparing the photographic copy for animated cartoons at present so popular in the moving pictures.

Cold Top Enamels

The modern "cold enamel", used by the photoengraver as a resist for the acid etching of zinc, was the discovery of a Bavarian photochemist, who found that shellac, rendered soluble in alkaline water, formed an emulsion which could be light-sensitized by incorporation of ammonium bichromate into the solution, and that the unexposed parts of the sensitized shellac solution were soluble in alcohol.

This invention is greatly speeding up and facilitating the photoengraving process, especially in the field of newspaper printing where zinc is almost universally used in place of copper because of its lower cost and quicker etching properties. Zinc becomes brittle or recrystallizes at the high temperatures to which copper must be subjected for "burning in" the photo-image on the enamel required to resist the etching agent.

Under this treatment the zinc plate would usually warp and frequently melt or become powdery.

Faced with this difficulty and dissatisfied with the tedious and slow albumen-ink process for making zinc half tones, the photoengraver sought for other methods, which would provide an enamel-like image but one which did not require subjection to intense heat to provide acid resistance.

Here was the solution to the problem for which photoengravers had been groping and this new method met with instant acceptance.

Cold top enamel has speeded up the production of line-cut and half-tone printing, and has therefore almost entirely usurped the field in newsprint and, in connection with recent developments in speed photography, it has had a marked influence in the production of the tabloid and illustrated sections contributing to increase in newspaper circulation.

The Pola-Screen in Photography

Polarized light used in photography to remove highly reflected rays and to alter light and shade, is effective in producing improved pictorial printing plates.

In the field of magazine advertising, where the types of paper and ink employed permit of obtaining more artistic effects than is the case with newsprint, direct photographic methods are now being employed and these methods will doubtless govern the style of half-tone printing in the future. By these methods the objects themselves are directly photographed upon the half-tone screen negative instead of a photograph of the object being first made and used as original copy for the half-tone reproduction.

The advantage of the direct half-tone method lies in the fact that it is much more realistic and a closer reproduction of the original since it avoids losses in detail and light and shade values which usually occur through rephotographing.

Whether this method or the usual indirect method is employed for making the half-tone picture, the use of a recently developed photographic device called the "Pola-Screen" is of inestimable value.

Good half-tone pictures depend upon good negatives. Reflected high lights have often made it impossible to secure satisfactory photographs, or necessitated costly retouching to eliminate the effects of glare caused by reflections from polished or glossy surfaces.

The "Pola-Screen" has been developed for use over the camera lens with a lens hood and screen holder either entirely to eliminate reflection or greatly subdue it. The advantage of this all photoengravers will immediately recognize and printers will not be slow to appreciate.

The vibration of light waves is not parallel to the direction of the rays, as are vibrations of sound, but at right angles to the ray and is usually dispersed in all directions. When a ray of light is polarized it vibrates in only one direction and by means of polarizing prisms this direction can be controlled. When two "Pola-Screens" are placed together with their vibration planes parallel, the second screen will pass the light polarized by the first; but as one screen is rotated, the light is diminished until, when the vibration planes are set at right angles, practically no light passes through and the polarizers are said to be crossed.

This is useful in photography because of the way in which surfaces reflect light. Reflected light is composed of two parts known as specular and diffuse components. A large proportion of the light reflected from a dull surface, such as chalk, is diffuse. The specular reflection produces gloss or glare such as occurs when light is reflected from glass or other highly smooth surfaces. This specular reflection, when at an angle of about 30 degrees from a plane surface, is polarized by the act of reflection and therefore may be removed by means of the "Pola-Screen." The single "Pola-Screen" over a lens can be rotated to a point where part or all of the objectionable specular reflection is cut out and the object may be photographed by the remaining diffuse light.

The effect of the use of this device in obtaining original pictures for reproduction and other uses will be very great, since the printed reproduction is directly dependent for its effectiveness upon the quality of the original photograph from which the half-tone printing plate is made. Polaroid screens can also be used to darken the sky in scenic photography without color distortion resulting as is frequently the case when the usual color absorption filters are used.

This invention will doubtless also greatly facilitate the observation and photographing of images through the microscope by removing the high light reflections from moist films of plant and animal cell tissues and the crystal surfaces of mineralogical specimens. Its value will be especially felt in the improved quality of reproduction of such micrographic pictures for educational purposes as illustrations in technical books.

The present demand for and consequent increased production of polaroid screens are tending to reduce their costs to the photographer. This will undoubtedly bring about a more widespread use of the instrument and greatly influence the character of certain types of photography which serve as sources for illustration printing.

Photoengraving may be called " the art preservative of all arts." In the printed reproduction of works of art, oil paintings, ceramics, and tapestries, the value of this invention as a contribution to photography will have a very definite effect in furthering the development of the art of fine printing.

Infrared Rays in Photography

The use of the longer wave lengths of light, called infrared rays, in recent photography to increase photographic visibility, will have its effect upon reproduction methods of the future and find its way into printed illustrations. By these rays which lie beyond the visible red of the spectrum, and specially sensitized photographic plates to absorb them, it has been found possible to take pictures in the dark by a light which is not visible to the human eye since the retina is not sensitive to its wavelength impulses. By this means also, combined with high altitudes through airplane flights, photographs have been made penetrating the clouds and over the earth's curvature to distances upward of 300 miles. Such photographic images are reproducible by printing. Photography has proved to be the extension of vision as the telephone and radio have been the extension of sound.

Three-Color Photography

Ours is a color-loving age; witnessed by the changes in the colors of modern wearing apparel from the once somber hues of black, blue, gray, and brown to the gaily variegated hues of the spectrum now everywhere seen in dress and objects of decoration.

Color photography has also undergone a transformation and many photographers are now able to obtain good color prints which are being more universally used in commercial fields, in national magazines, and in the rotogravure colored supplements of the leading newspapers.

Even as recently as 5 years ago a direct color-photo illustration in a magazine was a novelty on which the magazine capitalized. Though the advent of color photography in commercial fields is quite recent, the idea of reproducing color is by no means new. In fact, the idea was tried out some 50 years before the introduction of the first black-and-white photographic processes by Daguerre, Fox Talbot, and others.

The fact that color could be reproduced photographically was advanced by J. Clerk Maxwell in 1859 in a publication in the Proceedings of the Royal Society. He announced the theory that all the colors of nature could be matched by an admixture of the three primaries—red, green, and blue violet.

To demonstrate his theory, Maxwell took three photographs of the same object through three light filters each of which permitted only one of the three primary colors to pass. He then superimposed the three negatives by light projection through screens of the complementary colors and so resynthesized the colors of the original objects.

While this gave color images composed of light by projection on a screen it remained for Ducos du Hauron, the inventor of the photoengraving process, a few years later to outline the fundamentals of making color photographs on paper in which three colored images are superimposed in register on a paper support. Chemistry has played an important part in the development of this process to its present degree of perfection. The "carbro process" and the "dye imbibition transfer process" are the principal ones employed for making the colored prints. These methods are quite complicated and involve a knowledge of dye chemistry for their successful application.

The three negatives required for a color print are called "color separations" because in each the light ray has been separated or filtered out so that each negative is an actual record of one of the primary colors of which the original colored image was composed.

These color separations may be made with a camera which takes the three negatives at the same time by optically splitting the picture image into three separate images through semitransparent mirrors placed at suitable angles behind the camera lens. Separate plate holders are placed in position to receive these three images simultaneously, and in front of these plates are placed the color-absorbing screens required

to produce the proper color records. A number of color cameras are now being built for this purpose of simultaneous exposure of three-color negatives.

The catching in color of the ever-changing flow of nature, and the transient changes in the expressions of the human face so that they may be more faithfully reproduced in the magazines and the press, is the object which makes the advent of direct color photography of such portent in advertising.

The polychrome process of making colored prints was introduced for amateur use in 1931. This is quite a popular method because of its comparative simplicity, but does not always satisfy the critical worker.

A new process of color print making called the chromatome was introduced in September 1935, and gives excellent results although the working routine is not as simple as the operator might desire. It consists of making three prints, each on a collodion-backed emulsion which bears one of the primary colors. The three transparent prints are then overlaid on a final support to form the completed print.

The progress at present being made in direct color photography prophesies its use in the future for more universal color printing.

Its effectiveness consists in the true rendition of the colors of the original in all their vitality; and the textures of the original, such as of fabrics, are also very truthfully portrayed. This permits the making of press plates for printed reproduction much more nearly like the original than could be done if the copy were a hand-colored photograph.

In the field of moving-picture photography these principles of color application are being rapidly developed and it may be safely predicted that they may soon effect quite as marked a change as occurred when the silent pictures of the screen were converted into the "talkies." Already many promising effects have been obtained in color film pictures although the more delicate color tones have not yet been perfected for projection. The day of all color movies, with all that they imply in educational and amusement values for creating mass impressions and social influences, is certainly close at hand.

The possibility of reproducing more faithfully in print the colors, as well as the forms of great works of art, and the color harmonies of nature is also near at hand. Three color printing processes have been handicapped by the limitations imposed by pigments employed in making the inks. A large number of reds and blues and yellows have been used varying in chroma or color value and no standardization appeared possible. Through chemical research new pigments are being developed which may permit the use of three standard colors to give the full spectral range in printing by the tricolor process.

Pigments for Tricolor Printing

Monastral Fast Blue.—A notable development in color printing especially for tricolor reproduction processes is foreshadowed by the introduction of a new blue pigment.

The official announcement of the introduction of this pigment into commerce was made in January 1936.

It is noteworthy that, on reviewing the printing industry from the earliest times down to the present scientific period, while the basic processes are relatively ancient, the variations which have been made in their application reflect the progress made in the fields of chemistry and engineering. The constantly increasing use of colored inks in modern printing processes focuses scientific attention upon the subject of color pigments and their development to better serve the purposes of faithful trichromatic reproduction of original paintings or other works of art and colored objects.

Great difficulty has been experienced in color printing because no one set of red, yellow, and blue inks available for color process work was suitable for the reproduction of all designs. A blue ink suitable for one design would be quite unsuitable for others, and certain combinations of shades were practically unobtainable. The reproduction of a color design, for example, involving brilliant purples and vivid greens has led to an extensive investigation for finding a trichromatic blue, red, and yellow which could be standardized to reproduce all the spectrum tones with clear values and universally serve faithfully to render all the chromatic scale of the original subject. Some success has been achieved with yellow (hansa) and red (rhodamine) but no blue could heretofore be found which approached the ideal spectrophotometric analysis for pure color. However, from both practical printing tests and from theoretical viewpoints, monastral fast blue is filling a long-felt need in color printing.

This new pigment belongs to a class of compounds to which the name "phthalocyanine" or "kryptocyanine" was given in 1934. The first member of this class was discovered accidentally as a byproduct formed during the manufacture of phthalimide by the action of ammonia on phthalic anhydride contained in an iron vessel. This was found to be an iron compound of phthalonitrile. Monastral blue is the corresponding copper compound. Iron-containing blues are colors not fast to light and alkalis. This constitution therefore accounts for the remarkable resistance of this pigment to light and the action of molten potash, hydrochloric acid, and even concentrated sulphuric acid in which it dissolves without tinctorial loss.

It is interesting to note that in chemical structure it resembles the "porphyrins", which are the basis of many natural coloring matters, such as the haematin of the red blood corpuscles and the chlorophyll of green leaves.

It will be evidence to colorists in all branches of industry that this discovery is of epochal importance when it is recalled that the most widely used blue pigments at the present time, prussian blue and ultramarine blue, are sensitive to alkalis and acids, respectively, while the former is sensitive to heat deteriorations. The new pigment blue will withstand a temperature of 199° C. (390° F.).

The prime need for a pure blue constituent in trichromatic printing has long been emphasized; and since monastral blue shows a broader reflection band extending on both sides of the blue-green portion of the spectrum than the present standard blue-green ink, there is a definite probability that the complete solution of the problem of reproducing true color tones by means of only three standard pigments is not far off.

Quick-Drying Inks Which Speed Up Printing

A recent development in printing inks introduces both a new process and new materials employed. Such inks are said to be radically different in structure from the standard types. The solvent vehicles, unlike those in ordinary inks, pass off rapidly by vaporization upon the application of heat from a steam-heated drum over which the paper web passes after printing. This leaves the solids trapped and dry on the top of the sheet. At ordinary temperatures these new inks are inert and will not dry on the press parts. They dry in split seconds upon the application of sufficient heat or may be allowed to dry in the pile at moderate speed. In either case "offset" is eliminated. There is no penetration, no "dry back", no surface crystallization and no "skinning over."

It is claimed by their advocates that these new types of ink will "change the printing industry" as evidenced by their advantage to web-press printing where immediate "backing up" of the printed sheets is required, and to continuous process printing where the paper must pass through other fabricating steps, such as folding, scoring, coating, or cutting.

An obstacle to the rapid spread of this process lies in the fact that the printing presses must be remodeled to permit their use. Superheated drying drums and cooling drums must be added to the press in order that the printed web may pass over these to volatilize the ink solvent and thus quickly set the pigment upon the paper. However, this may constitute a decided new trend added to the present tendency toward increased speed in printing.

Mechanical Developments

In the realm of the mechanics of printing, progress is rapid. Automatic precision machinery is fast replacing the skill of handwork even for the more artistic achievements in printing.

Precision proof presses and precision color printing presses are being built today which attain a degree of accuracy in register heretofore thought unattainable in the printing of large-sheet impressions. Such presses can be operated at high speeds, in which the volume of production is increased without sacrificing quality.

Electrolytic etching may replace the hand etching process in producing copper half-tone printing plates, and this new method has recently been applied to the etching of zinc and aluminum with a high degree of success. Copper plates for rotogravure press cylinders and thin zinc or aluminum thin plates used in the "deep-etch offset" process have also been electrolytically etched in these machines, giving very sharp and clean printing plates and somewhat reducing the labor and time required by the customary methods. Technical and mechanical developments in the field of process photography and the manufacture of paper and inks are also aiding the progress of these more recent processes.

The number of minor mechanical inventions representing replacements and improvements on already highly developed printing machinery is too great for individual consideration. In general they are rapidly adding to an improved quality and facility in the art of printing.

Rotogravure

Gravure intaglio printing is offering serious competition to other printing processes both in monotone and in color. Experimenters are increasing in number, and their contributions, as new uses for the process come into being, are causing it to expand rapidly.

From the newspaper point of view improvement in type reproduction, greater rapidity of operation in preparing the printing cylinder, and a method for removing part of the lay-out at the last moment to replace it with "stop press" items, all constitute a rich field for research.

A quick method of fastening copper sheets to cylinders and eliminating the joint will solve numerous problems. It will enable plates to be made flat and shipped anywhere for use on web presses as well as on sheet-fed presses.

Elimination of the use of carbon tissue and the transfer process in making the press plate appear to be close at hand. Already a machine has been patented for coating cylinders automatically with any desired substratum. This will enable the assembling

of all negatives, pictorial and type together, laying them out in correct position, and making one composite film positive. For the printing of this positive on the light-sensitized cylinder directly, another piece of apparatus has been perfected enabling the operator to do the work very rapidly and efficiently.

Before a daily newspaper can go in for gravure—and it has been predicted that it will before long—etching of the plate must become practically automatic. A method of etching gravure in this way has lately been patented. The actual preparation of the copper plate, making the resist, printing the image, staging, and etching take less than an hour, and the actual etching only about 3 minutes. This method permits re-etching the plate where necessary just as easily as in regular half-tone work and a duplicate plate can be made exactly like the original.

The chromium plating of the finished plate surface and the substitution of harder metals than copper, such as brass, for the plate is leading to longer press runs and tending to put this process on an equal footing with stereotype plates in newspaper production.

Today the illustrated supplements, usually in sepia print but sometimes in colors, of many newspapers are made by the rotogravure process as a high-speed web-press product. Not much sheet-fed photogravure work is being done in this country at present, but Europe abounds in fine examples of this type of printing.

Developments along such lines indicate the tendency to increased speed and production in the output of this type of modern illustration work, and many moving-picture magazines of wide circulation are now employing the gravure process, by which means they are obtaining illustrations of artistic merit upon inexpensive paper stock. Here exists a strong indication of the influence of this type of printing in the near future.

The Teletypesetter

Printing telegraphs and typesetting by telegraph are very closely related. Both involve the selection of certain characters to be transmitted over a telegraph wire and printed. In the printing telegraph the characters are first selected and then printed on a sheet of paper and one copy or possibly a few carbons are made; while in typesetting by telegraph it is necessary to so arrange these characters that they can be afterwards used in casting type to print an indefinitely large number of copies.

In transmitting there are two general methods employed. Either a direct keyboard in which the depression of a character prints a corresponding character at the receiving end, or a perforated tape may be formed which can at any later time be fed through the machine to transmit the required message.

This latter method of the perforated tape is chosen for the teletypesetter devices for purposes of economy, speed, and convenience. Simultaneous perforation of tapes may be produced in several places and made to operate the linotype casting machines at any required speed without interruption, as would be the case if the transmitter were connected directly to the slug-casting machine.

The use of perforated tapes to operate linotype machines has also the advantage of permitting the machine to stop operation without the loss of any portion of the transmitted news as would be the case if the machine were directly connected to the source. This means also serves to speed up the work since one mechanic can feed the tapes to a half dozen linotypes at once, and the machines can be run to the limit of their capacity to cast the slugs. Perforated tapes containing the news story may be duplicated for running on several machines or may be transmitted again from one source through a wire hook-up to several cities to receive the signals directly and simultaneously on their linotype machines.

This invention will no doubt have considerable influence in newspaper publication and its effect may also be keenly felt in industrial employment situations.

Adaptations of the Photoelectric Cell to Printing

The Howey Engraving Machine.—A machine which makes an engraving upon zinc, suitable for newspaper reproduction, directly from a photograph without the use of a camera, has recently been developed. This machine was exhibited and demonstrated at the National Press Club in Washington, D. C., on October 22, 1931.

In principle the machine resembles the apparatus used for transmitting pictures by wire. The copy is "scanned" by a photoelectric cell receiving the impulses from a reflected needle beam of light. Current through the photocell thus varies continuously as the tone of the copy varies. The electrical output of the cell is amplified several million times by means of vacuum tubes and other apparatus similar to that used in an ordinary radio receiving set. This amplified variable current is used to operate an engraving tool which cuts the design directly upon a zinc plate.

The operation of the machine is fairly simple. Two cylinders, 3 inches in diameter by 10 inches in length, like miniature blanket and impression cylinders of a newspaper press are provided; one for holding the photographic copy, the other for holding the zinc plate to be engraved. These cylinders are geared to rotate at the same speed but in opposite directions, thus giving reversal to the cut for the purpose of printing. Enlargement or reduction of the image may be obtained

by varying the relative diameters of the rotating cylinders.

As the copy cylinder rotates, the continuous-tone photograph is brightly illuminated by a needle beam of light from which the reflected rays are focused by lenses upon the sensitive photoelectric cell. The carriage upon which the photocell is mounted moves parallel to the axis of the cylinder, thus viewing or "scanning" the copy in a helical path. The actual engraving operation, that is, the cutting of the thin zinc plate wrapped tightly around the opposing cylinder, is similar to the cutting of a thread upon a lathe. The V-shaped cutting tool is mounted upon a carriage which moves parallel to the axis of the cylinder as the photocell moves parallel to the axis of the copy cylinder. The cutting tool does not rotate, but cuts a wider or narrower line in the metal in accordance with the pressure exerted upon it. This depth of cut, and hence the width of the printing lines, varies with the tone value of the copy. When the photocell is viewing a dark spot of the copy, the tool makes a very light cut, thus removing very little metal and leaving more of the printing surface. When the photocell is on the high lights, the tool digs in deeper, cutting away more of the metal laterally, thus leaving less for the printing surface to receive the ink.

The printed image appears as a succession of lines of varying width or the lines may be formed in two directions at right angles to each other to produce a printing pattern similar to that obtained through the half-tone screen. This offers a trend of great promise and broad application in view of the possibility of connecting this instrument with radio transmission. Thus a printing-press plate could be directly formed by transferring any design to any metal through any distance without consuming time by photographing and metal etching.

The Semagraph.—The semagraph, a device which operates a linotype or Intertype machine by means of typewritten copy, may have a far-reaching effect in the near future upon the operation of linotype machines, since increased speed of these slug-casting machines can be obtained with the employment of fewer operators. An advantage lies in the fact that simultaneous operation of machines in different cities could be obtained by a wire hook-up and news more rapidly transmitted to the press by this means.

The device consists of two major units—a special typewriter which prepares the copy, and the semagraph unit which is attached to the composing machine in place of the keyboard and displaces the operator. This is another one of the recent inventions utilizing the photoelectric cell.

The photocell is mounted within the semagraph case immediately beneath the translucent copy sheet. A small electric light is mounted in a housing a few inches above the copy, which is synchronized to pass beneath the light by means of a perforated edge like that of a moving-picture film. Rays from the light source are focused upon the dots or signals beneath each literal character in the copy. These dots by interception of the transmitted light rays cause variations in the amount of light which falls upon the photoelectric cell, and these impulses are amplified to operate the mechanism which drops the linotype mats into their proper positions for casting the slugs.

A special motor-driven typewriter has been devised for preparing the semagraph copy. This machine simultaneously writes a double line of characters, the upper one in alphabetic letters and the lower one in a dot combination code resembling Braille writing for the blind. The copy typewriter perforates the paper edge in synchrony with the deposition of characters, and by means of using special scales it permits both the justification of the type lines and the deletion of any part desired.

Copy thus prepared can be fed into the slug-casting machine at the maximum speed possible for the casting operation. At present this is approximately six lines per minute. An experienced typist can, within a short time, learn the operation of the semagraph typewriter and can develop a much higher speed than that accomplished by the same typist on the standard typewriter. The typed copy can be accumulated and fed to the composing machine more rapidly than an operator could function.

The semagraph is adaptable not only for handling local press stories but also, with only a slight change in the equipment, for handling wire reports, so that no local typist is necessary, but only a linotyper to supervise fast-working machines.

Television in Relation to Printing

The quick transmission of photographs by means of radio and the photoelectric cell over long distances is an accomplished fact.

In an address on Communications Control in War before the Army Industrial College, Washington, on May 4, 1933, Col. David Sarnoff, Signal Corps Reserve officer and president of the Radio Corporation of America, said in part:

> Television experimental work has been carried on in close coordination with similar research in the field of facsimile transmission. Both developments seem destined to have revolutionary effect in our present methods of communication. Television is the art of converting light variations in such a way that they are able to modulate radio-frequency energy. Thus images may be reproduced in clarity and detail at some remote receiving station. Radio facsimile, which has already had widespread commercial application, is the rapid transmission of exact copies of smaller reproductions of printed

pages, documents, maps, drawings, photographs, or other printed or written data.

Much progress has been made with these two developments since ultra-short radio waves, in the bands below 5 meters, came under intensive study and exploitation within the last 2 or 3 years.

Both television and facsimile transmission will have the most vital bearing on our future communication methods and should be studied carefully in relation to communications and the national defense.

With equipment that has been in use on transoceanic facsimile circuits for some years, approximately 50 words of normal size may be transmitted per minute. The later carbon-recorder type of facsimile equipment with which we are now experimenting in our communications work has a speed capability of 400 words per minute. This is approximately 12 times the speed of the hand key in telegraphic work and greatly in excess of any automatic transmission employing the telegraphic code.

However, an entirely different line of facsimile development now in progress, based on the principles of television, appears more likely to cause a fundamental change in communications work. This method consists of recording, by specialized equipment, a 240-line television picture. By this method a facsimile transmission capacity up to 14,000 words per minute may be possible of ultimate attainment. Such transmission would accomplish what is at present done by 250 teletype machines or 450 telegraph operators typing messages by the Morse code. Experimental transmission of two newspaper pages, or about 14,000 words, may now be accomplished in 5 minutes. This time includes preparation, scanning, and recording.

Photographic Inventions

Through inventions pertaining to a finer particle size of the silver deposit in photographic films which eliminates the so-called "grain" effect upon enlarging, it is now possible to so reduce the size of a photographic copy as to be almost microscopic in proportions. By such a means upon a marginal perforated and reeled film it is possible to record a whole printed book, each page represented by one film exposure as upon a moving-picture-reel film. Such a film may be read through a lens or projected in enlarged sizes upon a screen for more convenient reading or photographic printing. This process is already being commercially applied in stores and banks for the recording of accounts and dispenses with the filing of great quantities of paper and printed matter.

The method is also being applied to obtaining permanent facsimile records of rare books and manuscripts, such as exist in our special libraries and archives, to preserve them for posterity in case of destruction of the originals.

It has been estimated that if one page of print can be reduced and recorded on one square millimeter of photographic film to permit of later enlargement to legibility, all of the books in the Library of Congress could thus be reduced and recorded on the space now occupied in that institution by the card catalogs of those books. If ever the complete recording and classification of all human knowledge becomes an active enterprise, photography and the microfilm will doubtless be the means for accomplishing it.

Microscopic printing may in the future result as a feature of this trend toward economy of time and space.

When the problem of the justification of the length of the type line is fully solved, the process of photocompetition may displace the use of metal in printing types to a large extent.

The solution of this problem may not be far off, for a typewriter which involves variable spacing of the letters is already within sight, and the same principle should be applicable to photocomposition. It is possible by the Uhertype method to project the images of letters by light beams onto a process film through the depression of lettered keys as on the typewriter or teletypesetter. The photographic film, moving before the projected type images, as the paper does in the carriage of a typewriter, receives the composition in a form which can be printed by the offset process in the same manner as photographic copy at present. This would eliminate the necessity of using metal type and producing an impression on paper which must be photographed on process film for reproduction. The perfection of such a process of photocomposition may well result in revolutionary changes in the world of printing by allying itself with the offset process.

In connection with producing moving pictures of X-rayed objects the problem of obtaining sufficiently strong light rays to permit rapid exposures in photographing, without dangerously increasing the X-ray voltages employed, has been solved by creating a new type of lens. The construction of this lens permits increased apertures to be used in bringing the light rays into correct focus on the film. An f. 0.48 lens has recently been built, having a short focal length of less than 7 millimeters, which transmits so great a percentage of the light rays that instantaneous photographs can be made of the X-ray screen and pictures taken almost in the dark. Through chemical research the increased sensitivity of photographic emulsions is also tending toward wider applications of photography. This will permit obtaining new records of marine life in under-the-sea photography at depths greater than the light penetration would heretofore permit. Such pictures, reproduced by the printing process, will no doubt affect the educational programs of coming generations.

Miscellaneous Trends in Printing

Many minor changes in the processes of printing as a result of recent technical developments in the preparation of paper, inks, etc., will have far-reaching effects

upon the printing of the future and corresponding influences upon social changes. Of such is the present tendency of paper manufacturers to produce a sheet which has the same qualities for ink reception on both sides of the sheet instead of possessing different printability on the opposite sides—wire side and felt side—as at present. In electrotyping reduplication, chemistry is playing the role of speeding up the electrodeposition of the copper shell as well as improving its grain structure by the addition of phenolsulphonic acid to the copper sulphate plating baths and by other means.

In molding plates for reduplication, a new wax mold is being developed to be laid upon a soft metal base with the purpose of displacing the ozokerite wax mold or the lead-molding process in the future.

There is a trend toward replacing metal printing plates in part by rubber-composition printing plates which in some cases have a greater facility for transferring inks (especially water-color printing inks) to the paper than do metal surfaces. Similar effects have been obtained by the electrodeposition of rubber from solutions upon the surface of metal plates and types.

The printing of tabulating cards for use in special accounting machines is a recent trend that should be especially noted. It is rapidly becoming possible by means of these perforated cards and the machines which sort them, to gather vast amounts of information of a statistical nature with a minimum of time and effort. Business is increasingly using this means for its analytical studies of financial conditions, and hospitals benefit by the ease of clinical classification and study of cases. Statistical studies of every sort, in every channel of human activity, may be made by this simple means. The printing of the punch cards requires great accuracy of register in order that they may function properly in the counting machines, and the paper from which they are cut must be of particular grade. A great many numbers may be printed in columns for perforation on a single card, and by combination of these numbers in a code system the uses to which they may be put in the gathering of information are practically limitless.

By special photographic methods, half-tone printing plates may now be made directly upon celluloid film, the celluloid serving as the printing surface in place of metal and the process of acid etching being entirely eliminated. These celluloid printing plates may be used directly on the presses or may be reduplicated by molding for electrotype or stereotype reproduction. They will function chiefly in the field of newsprint.

The substitution of a thin silver film on the electrotype wax mold in place of graphite powder to give the surface electrical conductivity may be effective in producing a better quality of printing plates.

The electroplating of harder metals, such as nickel or chromium, upon the surface of zinc-grained plates as used in offset printing and upon other metal printing surfaces is another recent technological trend toward obtaining a larger number of impressions from a single set of plates.

The substitution of synthetic resins for the greatly variable resin products obtained from natural sources and widely employed in the graphic arts is another step forward in the line of printing progress. Synthetic resins are susceptible of accurate technical control and duplication. Their substitution for dragon's blood and use in printing inks and press rollers are already on the way and will do much toward eliminating for the printer many troubles which result from the inconstancy of the materials he is forced to depend upon.

There are many other developments daily brought to light through scientific research as applied to printing which in large or small ways will unquestionably in their total effects exercise great influence upon the art of printing within the next few decades.

The function of the press as a means of mass communication through the channel of sight has no rival save the appeal by sound to the ear of the radio listener. To meet the public demand for news of current world events, quickly available and widely distributed, the printing processes have been developed through research and invention to a very high degree of efficiency. An example of this is shown in the recent press publication of pictures illustrating the events of the Olympic games in Germany and the civil strife at present raging in Spain, transmitted by radio waves simultaneously with the reports of the events themselves.

The potentiality of printing for both good and evil as an instrument of social influence, education, and the determination of public policies is almost without limitation. Like many other human inventions it derives its character from the motivation of human actions and the uses to which it is subjected. No prophecy could here be ventured as to the future course of this inherent power of printing.

In the midst of the complex social order representing the present status of civilization it must be left to the capacities of the imagination to delineate a picture of the social and economic changes which may occur in the generations immediately succeeding our own as a result of these trends in printing. Certainly the development of the mechanical means of world-wide communication and the exchange of knowledge is rapidly advancing and extends great opportunity for social intercourse among all peoples.

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The great variety and multiplicity of patents which are now being issued in the field of printing and photography are an augury of this progress. It would not be possible within the scope of this article to record these ever-occurring inventions and evaluate their possible influences upon the future of printing as one of the great channels of communication. We have therefore only touched upon a few illustrative examples.

It would not be fitting to conclude without paying tribute to the powerful agency which is bringing about these remarkable changes in a long-established and once very conservative trade. Scientific research, applying the principles of chemistry and physics to the solution of problems of cause and effect, is rapidly opening the doors once locked against progress by a jealous secrecy formerly maintained throughout the craft. The slogan of the modern printer craftsman is "Share your knowledge", and this newborn spirit is carrying forward the ancient art by leaps and bounds.

Paper manufacturers, machine builders, ink makers, and process printers are now in cooperative contest to improve the quality, increase production, and reduce the costs of printing by scientific methods of procedure and control. This awakening to the value of scientific research in the printing industry is not local to the United States but is world-wide in scope. In some countries a national interest is being shown in organizing groups for investigational research.

The investment of all cooperative investigation applied to printing and photography as related to printing must return in the future in the form of great dividends to the progress of this venerable art.

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V. POWER

By A. A. Potter and M. M. Samuels[1]

I. THE PRODUCTION OF POWER

America's Power-Producing Capacity

The United States of America leads the entire world in the amount of power available and used. The major users of mechanical power are manufacturing industries, agriculture, mines and quarries, transportation systems, and homes. The power used by manufacturing industries, agriculture, mines and quarries is either manufactured in isolated plants or is purchased from a public utility which may be under private or public ownership.

Transportation systems, which include motor vehicles, railroads, marine propulsion (steamships and motor ships), and airplanes usually carry their own power generating equipment; an exception to this are electric railways, busses with trolleys, and electric street cars which operate on current supplied from a central station at some convenient point.

Domestic power users, including urban and to an increasing extent also rural customers, depend for their power supply upon a public utility central station.

The mechanical power available in this country in 1935 was about 1,231 million horsepower distributed as indicated in table 11.

TABLE 11.—*Distribution of power in the United States*

Electric central stations	44, 670, 000
Industrial power plants	20, 133, 000
Electric railway plants	2, 500, 000
Isolated nonindustrial plants	1, 500, 000
Mines and quarries	2, 750, 000
Agricultural prime movers	72, 763, 000
Automobiles, busses, trucks, and motorcycles	965, 000, 000
Airplanes	3, 500, 000
Locomotives	88, 000, 000
Marine	30, 000, 000
Total horsepower	1, 230, 816, 000

The Electric Central Station Industry.—At the end of 1935 this industry had an installed generating capacity of 33,446,400 kilowatts, which is equal to 44,670,000 horsepower. Of this capacity public utilities under private control had an installed capacity of about 94.5 percent of the total; those under public control about 5.5 percent of the total.

The installed electric generator capacity in this country of nearly 33.5 million kilowatts may be compared with 12.8 million in Germany, 10.1 in France, 7.25 in Great Britain, 6.1 in Canada, 5.47 in Soviet Russia, and 5.3 in Japan, and 4.55 million kilowatts in Italy. On the per-capita basis, the installed generator capacity of the United States is 0.27 kilowatts as compared with 0.19 in Germany, 0.24 in France, 0.16 in Great Britain, 0.59 in Canada, 0.033 in Union of Soviet Socialist Republics, 0.077 in Japan, and 0.11 in Italy.

Of the installed generating capacity in electric central stations, fuel prime movers, i. e., plants utilizing fuel, represented as of December 31, 1935,[2] a total of 24,488,400 kilowatts, or 73.2 percent and hydroelectric plants, 8,958,000 kilowatts, or 26.8 percent. Of the fuel prime movers in electric-power stations, steam plants represented 98 percent, and internal-combustion engines made up 2 percent. About one-half million kilowatts installed capacity in Diesel engines was reported in electric-generating stations at the end of 1934. More than half of the Diesel capacity, or 280,000 kilowatts was in municipal power plants. The trend in the sources of power used in electric central stations is shown by table 12, compiled from data published by the National Electric Light Association in 1931 and by the Edison Electric Institute in 1935.

TABLE 12.—*Horsepower of installed capacity in electric-generating stations*

Year	Steam plants	Internal-combustion engines	Water power	Total
1902	1, 394, 395	12, 181	438, 472	1, 845, 048
1912	4, 949, 778	111, 035	2, 469, 231	7, 530, 044
1922	14, 171, 222	302, 995	5, 822, 018	20, 296, 235
1930	31, 000, 000	600, 000	11, 600, 000	43, 200, 000
1935	32, 000, 000	670, 000	12, 000, 000	44, 670, 000

The Federal Power Commission has reported for the year 1935 the capacity of publicly owned hydroelectric plants as 853,000 kilowatts. Of this total 455,000 is represented in municipal plants, 38,000 in the Bureau of Reclamation, and 360,000 kilowatts in generating capacity as owned and operated by State and Federal Governments.

[1] Section I of this chapter, The Production of Power, was contributed by A. A. Potter, dean of engineering, Purdue University; president, American Engineering Council. M. M. Samuels, electrical engineer, Federal Power Commission, prepared the second section, Transmission and Distribution of Electrical Energy.

[2] Edison Electric Institute Bulletin, February 1936 (estimates by the Federal Power Commission for 1935 are 34,446,400 kilowatts distributed in the following manner: Private, 31,578,941; municipal, 1,973,446; and Federal and State Government, 467,949 kilowatts). One kilowatt=1.33 horsepower.

In the national power survey Interim Report of 1935, published by the Federal Power Commission, the total production of electricity by the major utility systems of the country is given for the year 1933 as 76,882 million kilowatt-hours, of which 59 percent was generated by steam power, 41 percent by water power, and only 0.09 percent by internal-combustion engines, including Diesel plants. As of December 31, 1935 the Edison Electric Institute in its bulletin of February 1936, gives the kilowatt-hours generated for the year 1935 as 92,328.3 million kilowatt-hours, of which 59.5 percent was generated by fuel-power plants and 39.5 percent by waterpower.

The growth of the so-called electric light and power industry is indicated by comparing the output of 92 billion kilowatt-hours in 1935 with 80 billion in 1927, 25.5 billion in 1917, 11.5 billion in 1912, 6 billion in 1907, and only about 2.33 billion kilowatt-hours in 1902.[3] Since 1882 and until 1929 the output of electric central stations has practically doubled every 5.5 years.

The present electric output in this country of over 92 billion kilowatt-hours should be compared with 31 billion in Germany, 20.7 billion in Great Britain, 20.5 billion in Soviet Russia, 19.3 billion in Canada, 18.16 billion in Japan, 15.3 billion in France, and 11.9 billion kilowatt-hours in Italy. These figures[4] of electric output on the per capita basis are 678 for the United States, 398 for Germany, 405 for Great Britain, 97 for Union of Soviet Socialist Republics, 1,629 for Canada, 269 for Japan, 356 for France, and 265 kilowatt-hours for Italy.

The revenue[5] of the electric utility industry from sale of energy to ultimate consumers has grown in this country from 84 million dollars in 1902, to 282 million in 1912, to 1,029 million in 1917, to 1,661 million in 1927, to 1,991 million in 1930, and to 1,921 million dollars in 1935. At the same time the capital invested[5] in this industry has increased from 505 million in 1902, to 2,176 million dollars in 1912, to 4,456 million in 1922, to 11,850 million in 1930, and to 13,100 million in 1935, the figure for 1935 being the estimate of the Federal Power Commission.

The Edison Electric Institute in its statistical bulletin No. 2 (table XX), dated April 1935, gives the total investment of electric generating systems as $12,664,376,952 for 1934, of which 95.75 percent was invested in private electric utilities and 4.25 percent in municipal plants.

The electric central station industry which had its beginning in September 1882, has developed during the past 54 years so that it ranks fifth among all industries of the country in the amount of money invested and thirteenth in point of number of employees and the value of its product. The following data about this industry are significant:

In the 30-year period from 1902 to 1932 the Federal Power Commission reports that the value of the electric central station industry's plant and equipment increased 25 times; its income from electric service, 23 times; its generating capacity, 29 times; its output, 32 times; and its employees, 8 times.

At the beginning of 1935 the electric utility industry consisted of approximately 1,620 privately owned operating companies and 1,930 municipal systems.

The average selling price of electricity in cents per kilowatt-hours for household use[6] has been reduced from 25 in 1882, to 16.2 in 1902, to 9.1 in 1912, to 7.38 in 1922, to 5.58 in 1932, and to 5.03 in 1935. The United States Bureau of Labor statistics, with the 1913 index as 100, gives the index for 1882 as 287, for 1902 as 186, for 1912 as 104.6, for 1922 as 85, for 1932 as 63.1, and for 1935 as 57.8.

The average cost per kilowatt-hour for large consumers of power[5] has decreased from 1.69 cents in 1921 to 1.29 cents in 1935. The wholesale cost of power delivered to market centers has been estimated by F. F. Fowle, consulting engineer of Chicago to be 1.25 cents per kilowatt-hour and the cost of distribution 3.05 cents, making the average cost 4.3 cents per kilowatt-hour.

The use of electricity in kilowatt-hours per annum by domestic customers[5] has been increased from 264 in 1913, to 359 in 1922, to 548 in 1930, and to 673 in 1935. At the same time the average annual bill paid by domestic customers has changed from $22.97 in 1913 to $26.50 in 1922, to $33.04 in 1930, and $33.85 in 1935. Thus the use from 1913 to 1935 has increased over two and a half times while the cost for the larger amount was only 47 percent more in 1935 than it was for the smaller amount in 1913.

The number of wired homes in this country[7] has increased from about 3 million in 1912 to 10¼ million in 1922 to 20½ million in 1930, and to about 21¼ million in 1935.

The electrified farms of the United States, served by central stations,[6] increased from 177,561 in 1923 to 649,919 in 1930 and to 788,795 in 1935. In addition to these figures 250,000 farms are being served by individual electric-lighting plants.

The number of customers served by the electric central station industry, has increased from 583,000 in 1902 to 3,837,518 in 1912, to 12,709,868 in 1922, to 24,-

[3] Compiled from figures published in the Electrical World and by the Edison Electric Institute.
[4] Supplied by the Federal Power Commission.
[5] Statistical supplement, N. E. L. A., 1931.
[6] Statistical bulletin, Edison Electric Institute, April 1935.
[7] Supplied by the Federal Power Commission. Source: Edison Electric Institute bulletins.

664,000 in 1930, and to 25,370,966 as of December 31, 1935.

The per capita use of electricty has increased from 30 kilowatt-hours per annum in 1902 to 734 in 1935, or more than 15 times as fast as the population growth of this country. (The maximum per capita use was 762 for the year 1929.)

Industrial Power Plants.—These in 1934 had a generating capacity of about 15,000,000 kilowatts,[8] which is equal to 20,133,000 horsepower. The generating capacity of industrial power plants has increased from 3,411,000 horsepower in 1880, to 16,803,000 in 1910, to 19,900,000 in 1920, and to about 20,000,000 in 1935.[5]

The census figures for 1929 gave a total of 42,514,358 horsepower for 192,004 industrial establishments, excluding generators.

The trend in different types of power equipment in industrial power plants is shown, in horsepower, in table 13.

TABLE 13.—*Industrial power plants*

Dec. 31—	Steam plants	Internal-combustion engines	Water power	Power generated	Power purchased	Total power used
1899.....	8,189,564	134,742	1,454,112	9,778,418	182,562	10,097,893
1909.....	14,228,632	751,186	1,822,888	16,802,706	1,749,031	18,675,376
1919 ...	17,036,210	1,241,829	1,765,131	20,043,170	9,284,499	29,327,669
1927. ...	16,941,098	1,170,759	1,783,711	19,895,568	19,144,995	39,040,563

The above table shows that purchased power which represented in 1899 only 1.8 percent of the total power used by industry had increased in 1919 to nearly one-third and in 1927 to nearly one-half. No accurate data could be secured for 1935 but the figures for that year, it is believed, do not differ greatly from those for 1927. The rapid electrification of industry is indicated by the increase in the total horsepower of electric motors used in factories from 492,936 in 1899, to 4,817,140 in 1909, to 16,253,702 in 1919 and to 30,361,106 in 1927. The percent of electrified tools and machines of American industry has increased from 4 in 1899, to 23 in 1909, to 53 in 1919, and to 75 percent in 1927.

Electric Railway Plants.—Those not supplied with current by the electric-light and power plants had an installed capacity during 1935 of about 2,500,000 horsepower. Street railways and rapid-transit lines during 1934 generated 2,276 million of kilowatt-hours in their own plants and purchased during the same year 5,005 million kilowatt-hours,[9] the purchased power representing 68.7 percent of the total.

Mines and Quarries.[10]—The installed or available capacity of electric motors in mines and quarries is at present about 5,000,000 horsepower, having increased from 221,159 horsepower in 1909. However, the prime-mover capacity has decreased from 3,384,548 horsepower in 1909 to 2,743,025 horsepower in 1929. In 1929 mines and quarries purchased 5,382 million kilowatt-hours and generated 2,081 million.

Agricultural Prime Movers.—In Bulletin 157 of the United States Department of Agriculture, dated April 1933, the total horsepower used in agriculture is given as 70,501,795. This estimate includes 25,000 steam engines averaging 40 horsepower and 1,000,000 windmills averaging 0.33 horsepower each; also 18,161,386 horses and mules at 0.95 horsepower each; 920,021 tractors at 23.9 horsepower each; and 1,131,108 gasoline engines at 2.68 horsepower each.

It is estimated [11] that the total available horsepower on American farms as of January 1935, mechanical, wind, and animal, was about 72,763,000. The mechanical horsepower available was about 56 percent of the total, or 40,750,000 horsepower.[11]

The number of farm tractors in use has been reported by the United States Department of Agriculture to have increased from 80,100 in 1918 to 852,989 in 1929 and to 1,123,351 at the beginning of 1935.[12]

The power developed by all prime movers on American farms was estimated at 16½ billion horsepower-hours during 1935 [11] or the equivalent of about 11 billion kilowatt-hours. Mechanical power represented about 5½ billion kilowatt-hours.

Isolated Nonindustrial Plants.—Under this classification are not included plants used in agriculture or in mines and quarries, but all other isolated plants such as are installed by the Government in public buildings, hotels, and for other stationary uses not included before. These are estimated to have a capacity of about 1,500,000 horsepower.

Motor Vehicles.—The motor vehicles of the United States have more available power than all other producers of power combined.

In 1935 there were in use in this country 22,589,660 automobiles, 3,511,061 trucks, 66,386 busses, and 95,633 motorcycles, a total of 26,262,740 motor vehicles.[13] The entire world, outside of the United States of America, had in use in 1935 only 11,108,157 motor vehicles, which included 7,257,000 for all Europe, 1,926,231 for the Americas (except United States),

[5] Statistical supplement, N. E. L. A., 1931.

[8] Frank F. Fowle before Midwest Power Engineering Conference based the figure of 15,000,000 kilowatts for 1934 upon census statistics for 1929 with minor allowance for growth.

[9] Data supplied by the Federal Power Commission.

[10] Data from census report of 1929 and from industrial report prepared by the national power survey.

[11] Estimate by S. H. McCrory, Chief, Bureau of Agricultural Engineering, United States Department of Agriculture.

[12] Aug. 1, 1935, issue of Farm Implement News.

[13] Automotive Industries, statistical issue, Feb. 22, 1936.

590,935 for Asia 874,981 for Oceania and 458,911 for Africa.

The more than 26 million motor vehicles in the United States in 1935, should be compared with about[13] 20 million in 1925, 9¼ million in 1920, 2½ million in 1915, less than ½ million in 1910, 78,000 in 1905, 8,000 in 1900, and 4 in 1895.

Passenger cars have increased from 1 per 12.9 people in 1920 to 1 per 5.6 people in 1935.

The Automobile Manufacturers Association in its 1935 edition of Automobile Facts and Figures has estimated that about 4½ million people are employed directly and indirectly by the automotive industry not including raw material workers which add about 500,000 more.

Estimating the power of automobiles at an average of 30 horsepower (the taxable horsepower of the two most used automobiles) and that of trucks and busses at 80 horsepower, the available power in automobiles is about 678 million horsepower and that in trucks and busses 286 million. If the power available in motorcycles is added, the total will approach about 965 million of available horsepower. (If the brake horsepower is used as a basis, instead of taxable horsepower, the power available in the motor vehicles of the United States would exceed 2 billion, as the brake horsepower is about 2.5 times the taxable horsepower.)

The horsepower-hours output of the American motor vehicles, during 1935, has been calculated to be about 130 billion which is the equivalent of about 87 billion kilowatt-hours.

Airplanes.—During 1935 airplanes in use have been estimated at 9,072. Assuming 400 horsepower as the average power of an aairplane, this type of transportation represents about 3½ million of available horsepower.

Railroads.—The Association of American Railroads reports for February 1936 a total of 45,179 locomotives for class I railroads. This figure includes all types (steam, electric, and Diesel) and is made up of the classes indicated in table 14.

TABLE 14.—*Locomotive statistics*

Type of service	Number	Aggregate tractive effort in pounds
Freight locomotives	28,493	1,561,490,571
Passenger locomotives	8,238	301,428,625
Switch locomotives	8,448	336,395,866
Total	45,179	2,199,315,062

Included in the above classification are the data given in table 15, about electric and Diesel locomotives.

[13] Automotive Industries, statistical issue, Feb. 22, 1936.

TABLE 15.—*Electric and Diesel locomotives*

Type of service	Electric aggregate		Diesel aggregate	
	Number	Tractive effort	Number	Tractive effort
Freight	295	20,459,656	3	112,750
Passenger	348	20,408,182	6	272,800
Switch	126	5,185,450	127	6,776,304
Total	769	47,053,288	136	7,161,854

The Coordinator of Transportation in June 1934 estimated the average horsepower of steam locomotives in use as 1,922. Since this report was prepared over 4,000 locomotives, mostly the smaller ones, have been scrapped. Thus an average figure of 1,950 for the horsepower of the locomotive now in use is fairly accurate; taking this figure, the total present horsepower of locomotives is about 88 million.

Marine Transportation.—The power available in all types of marine transportation has been estimated for the United States as 30,000,000 horsepower.

Total Power Produced and Used.—The total of the above 10 classifications indicates that the installed or available power in the United States in 1935 was 1,231 million horsepower. This, divided by an estimated population of 127½ million for 1935, gives about 10 horsepower per capita of our population, the equivalent of more than 100 slaves. In 1899, R. H. Thurston estimated the use of power in this country at 25 million horsepower, or the equivalent of about two man-power per capita of the population. Thus man's productive capacity has increased 50 times during the past 35 years.

While the power available for use in motor vehicles is about 20 times greater than that available in electric-generating stations or on farms, the actual energy used per year in kilowatt-hours has been calculated as 87 billion for automobiles as compared with over 92 billion in central electric stations and with 11 billion kilowatt-hours for power on farms.

Requirements for Production and Utilization of Power

Three requirements are essential for the production and utilization of power: First, a source from which energy may be derived; second, a prime mover capable of transforming this energy into work; and third, a means for making the power easily available for use.

The term "prime mover" is applied to the main power-generating unit of a power plant. Thus the steam engine or the steam turbine is the prime mover of the steam power plant; the gas or oil engine is the prime mover in the internal-combustion-engine power

plant; and the water wheel or water turbine is the prime mover in the hydraulic power plant.

Energy Resources.—The principal source of all energy is the sun. The sun's rays, however, cannot be utilized directly to any appreciable extent for power production and secondary sources of energy must be made available through fuels in different forms, such as coal, petroleum, oil or gas, waterfalls, and windmills.

Fuels and waterfalls are the major energy resources for mechanical power production. Fuels which play no part in the civilization of the past, are the major mechanical-power producers of today.

In 1930, the electric central stations, which include electric light and power plants as well as electric railway and manufacturing plants, which sell all or a portion of their output to the public, consumed nearly 43 million tons of coal. In addition they used oil and gas equivalent to 7¾ million tons of coal, for both petroleum and natural gas have become factors of considerable importance in the generation of electricity.

During 1935 over 18 billion gallons of gasoline were consumed by the motor vehicles of this country as compared with only about one billion in 1915. In this connection it is interesting to note that while in 1909 gasoline represented less than 10 percent of petroleum distillates, in 1934 it represented 44 percent.

Wood is but little used for fuel except in remote places, where timber is the cheapest fuel, or in special cases where sawdust, shavings, and wood cuttings are byproducts of manufacturing operations.

Alcohol, made from agricultural crops or synthetically, will have to be greatly reduced in price to be economically attractive in this country, as a substitute for petroleum.

Wind as a source of power is practical in localities where windy weather is prevalent, where very little power is needed, and where the use of mechanical power can be suspended during calm weather. The windmill is not practical for the generating of electricity, as it cannot be built to develop large amounts of power, has poor speed regulation, and is expensive per unit of power capacity. All wind prime movers lack reliability and labor under the disadvantage of low average availability.

The Statistical Abstracts of the United States for 1933 indicate that the United States of America has about 59,166 million horsepower of potential water-power energy available during 50 percent of the time and 38,110 million available 90 percent of the time. Some estimates have placed the maximum potential output of water-power plants of this country at as high as 123 billion kilowatt-hours.

The Federal Power Commission in its Interim Report (Power Series No. I) of 1935 has estimated the undeveloped water power of the United States at 52,628,900 kilowatts installed capacity of which about two-thirds of the sites are in the Pacific Northwest and Pacific Southwest, and less than a fourth in the Northeast or Middle West. This report records that the sections of this country which embrace 75 percent of the population and 80 percent of the fuel production have about 20 percent of the undeveloped water power. The sections which comprise 25 percent of the population and 20 percent of the fuel resources have about 80 percent of the undeveloped water power. Forty-two percent of the undeveloped water power is located in the Pacific Northwest. Of the practical water-power developments of this country about two-thirds are located west of the Mississippi River, that is, in a section of the country where power requirements are only about one-third of the total. It is fortunate, however, that regions in the United States which are far removed from coal and other fuel resources are often favored with practical water-power sites.

Prime Movers.—Only those prime movers which utilize the heat energy of a fuel or of waterfalls are significant for power production. Such prime movers do work by virtue of motion given to a piston, or to blades on a wheel, by steam, gas, or water which must be under pressure. This pressure in the case of the steam, gas, or oil engines is obtained by utilizing the heat of a fuel; while in the water wheel, work is obtained by utilizing the potential energy of water empounded behind a dam.

In the steam-power plant a fuel like coal, oil, or gas, is burned in a furnace and its heat of combustion is utilized in changing water into steam at high pressure in a special apparatus called a boiler, or, more correctly, a steam generator. The high pressure steam is then conveyed by pipes to an engine cylinder where its energy is expended in pushing a piston; the reciprocating motion of the piston is changed into rotary motion at the shaft by the interposition of a connecting rod and crank. Another method is to direct high pressure steam so that it will strike blades on a wheel and produce rotary motion direct, as in the case of the steam turbine.

In gas and gasoline engines, the fuel, which must be in a gaseous state as it enters the engine cylinder, is mixed with air in the proper proportions to form an explosive mixture. It is then compressed and ignited within the cylinder of the engine, the high pressure, produced by the explosion, pushing on a piston and doing work. Gas and gasoline engines belong to a class called internal-combustion engines, and differ from the steam engine, which is sometimes called an external-combustion engine, in that the fuel is burned inside of the engine cylinder instead of in auxiliary apparatus.

The Diesel oil engine is also an internal-combustion engine but differs from the ordinary gasoline engine in the following details: In the gasoline engine, or in other types of the so-called Otto cycle engines, an explosive mixture of fuel and air is prepared outside of the engine cylinder; this explosive mixture is introduced into the engine cylinder, is there compressed by a piston and is ignited by an electric spark, the compression pressure before ignition varying ordinarily in the case of automobile engines from 70 to 120 pounds per square inch. In the case of Diesel engines only air is compressed by the piston and the compression pressure is about 500 pounds per square inch; oil fuel, mixed or unmixed with air, is injected at the end of the compression process and the high temperature of the highly compressed air ignites the fuel, an electric spark or other auxiliary ignition device not being necessary to burn the mixture.

Water power is a function of the amount of stream flow and of the hydraulic head available. The water wheel or water turbine converts the energy possessed by moving or falling water into work. The wheel is made to revolve either by the weight of the water falling from a higher to a lower level, or by dynamic pressure which is produced by changes in the direction and velocity of flowing water. The total power available in water when in motion depends on the weight of water discharged in a given time and on the head or distance through which the water is allowed to fall.

Electricity as the Link Between the Prime Mover and the User.—Power without machines to be driven is useless. Thus the power producing equipment must be considered in association with some means of transmitting the power from the place where it is generated to the machine where it is used. For more than 100 years after the perfection of the steam prime mover by Watt transmission of power from the engine to the power-driven machines was entirely by mechanical means such as belts, chains, ropes, discs, cams, levers, gearing, and shafting. As late as 1880 no less an authority than the great English scientist Osborne Reynolds advocated the use of rope drives in preference to electric-power transmission, which he considered to be impractical. A new impetus to the use of mechanical power was given when electricity proved to be a practical link for transmitting power over great distances.

While Watt's improvement of the steam engine marks the beginning of the Age of Mechanical Power, the greatest impetus to its use dates back to September 1882 when the Pearl Street electric-generating station was started in New York City. Electricity has created a large market for power and has definitely influenced industry, transportation, communication, illumination, and the general mode of living. Electricity makes mechanical power available where wanted and when wanted.

Electricity, distributing and utilizing mechanical power most effectively, is the living force of our present civilization; the electric motor, made in sizes from a fraction of a horsepower to 40,000 horsepower, has provided a most practical means for driving the tools of industry and for relieving humanity from drudgery in the home and on the farm; electric traction, electric illumination, electric communication, the cinema, and numerous appliances and devices of the present age which save time, reduce labor, and provide amusement were made possible by electricity, the most important link between the prime mover and the use of mechanical power.

Batteries, or chemical generators of electricity, are used mainly in places where the current requirement is small, as in connection with ignition systems of low-pressure internal-combustion engines, for telephone communication and stand-by service. One type, the primary battery, generates electrical current by means of direct chemical action between certain substances; another type, the storage battery, requires charging with electricity from some outside electric source before it will give up electricity.

For the generation of electricity in large amounts electric dynamos are used. They are built in capacities which range from one kilowatt (1⅓ horsepower) to 160,000 kilowatts and even larger, and are driven by steam prime movers, internal-combustion engines or hydraulic turbines. Dynamos generate either direct or alternating current. Direct current is advantageous for certain industrial uses, such as for some motors in factories, street railway operation and elevator service. About 95 percent of all the electricity generated in the electric central stations of the United States of America is alternating current. Alternating current electricity can be generated at high voltages and its voltage can be easily increased or decreased by means of transformers, so that it is more practical than direct current for the economical transmission and distribution of electrical power.

The detailed problems of "Transmission and Distribution of Electricity" are treated in a separate paper under the authorship of M. M. Samuels of the Federal Power Commission.

Economy of Mechanical Power Production

Power generation should be considered as a manufacturing problem in which power is the product of the power factory or power plant. The materials which go into the manufacture of power in the case of fuel-burning plants are fuel (coal, oil, or gas), lubricating oil, and water; in the hydraulic power plant no

fuel is used. The cost of these materials together with labor and superintendence make up the operating expenses. The total cost of the manufactured product, mechanical power, depends upon these operating expenses, upon fixed charges on plant investment, and upkeep costs. The fixed charges include interest on investment for machinery, land, buildings, and for other capital charges; also taxes, insurance, depreciation, and obsolescence. In all cases charges for the product must be determined with due fairness to the power producer as well as the user.

Cost of Power.—The cost of generating power is only a part of that which must be met by the consumer. A number of factors influence the actual cost, some of which have to do with the investment in the plant, others which relate to the utilization of the plant, and still others which are concerned with operating expenses. Interest, taxes, insurance, and provisions for depreciation and obsolescence influence the fixed charges on plant investment, as do the requirements for reserve capacity and the extent to which the plant is utilized, or plant-capacity factor. Mr. F. F. Fowle in a paper which he presented before the Midwest Power Engineering Conference at Chicago on April 22, 1936, stated that "a complete electric utility of average size requires at present an investment in the order of $365 per kilowatt of installed capacity, or $520 per customer served. Approximately 38 percent of this amount is invested in generating plants, 24 percent in transmission lines, and 38 percent in local distribution systems. * * * The annual charge for interest, taxes, insurance, and depreciation on the investment constituted in 1935 about 65 percent of the whole cost of service." The 1935 investment of electric utility systems is given by Mr. Fowle as 13 billion dollars, of which 4.8 billion is in generating plant; 3 billion in transmission system; 4.7 billion in distribution; and 500 million in miscellaneous equipment.

In considering the fixed charges for a stationary electric generating plant a number of factors must be considered among which the following are of major importance:

The power plant proper with its land site, buildings, and machinery. The cost of power plants per kilowatt vary with the type of prime mover, size, location, and design. In general, large steam generating stations may be built at a cost of $75 to $125 per kilowatt capacity.

The Federal Power Commission has made a study of 80 of the largest steam-electric power plants constructed since 1920, to determine the cost per kilowatt of installed capacity. The results of this study are given in table 16.

TABLE 16—*Relation of cost to capacity of steam-electric plants*

Price per kilowatt range	Kilowatts capacity	Percent of total capacity	Number of plants
Under $70	247,000	2.6	4
$70 to $80	1,073,500	11.4	6
$80 to $90	859,500	9.1	8
$90 to $100	822,500	8.7	7
$100 to $110	2,200,000	23.2	15
$110 to $120	977,950	10.4	11
$120 to $130	1,566,750	16.5	11
$130 to $140	934,500	9.8	11
$140 to $150	182,860	1.9	2
$150 and over	602,000	6.4	5

Hydroelectric station costs vary with the topography and geology of the site, water available, needs for storage and auxiliary equipment.

Transmission and distribution costs, which include transformers to step up the voltage, transmission lines, step-down transformers, and distribution systems. Ordinarily, electricity is generated in central stations at voltages of 11,000 to 13,500; this must be stepped up to higher voltages for transmission to market. The cost of transmission lines will depend upon the distance electricity must be transmitted, the amount of electricity to be transmitted, and the cost of rights-of-way. Usually step-down transformers are used at load centers to reduce the voltage to suit local conditions. Then there are distribution substations and feeders to the point of use. Residential customers must be supplied with current at low voltages and in small amounts; in such cases transmission and distribution costs are often greater than the interest costs for the power station with its equipment. Industrial customers who require large amounts of energy and can frequently take it at high voltage involve less expensive transmission and distribution costs. While average cost data are easily secured, it is exceedingly difficult to calculate the actual cost per kilowatt for any special service, because of the great difficulty of allocating properly, between different classes of service, the numerous items of cost which combine to give the total cost of service.

Provisions for depreciation and obsolescence depend not only upon the actual life of the equipment but upon the useful life which often depends upon progress in the art. Thus in the case of certain power-producing machinery, improvements in design and construction have frequently resulted in conditions which made it practical to replace a prime mover in 3 to 10 years with more modern equipment. Obsolescence, not merely wear, influence equipment replacement costs. Thus adequate allowance for depreciation and obsolescence should be considered in all calculations of power costs.

Needs for reserve capacity depend upon the types of equipment and facilities available for meeting emergencies. Thus interconnection in the case of central electric generating stations has reduced the need for reserve capacity. Cooperation between industrial and utility plants is advantageous in reducing the necessity for spare units in either or both types of plants.

Taxes are an important item in the cost of power. In some fuel-burning plants taxes (local, State, and national) are approaching the cost of fuel. The Edison Electric Institute has reported that the ratio of taxes to operating income has increased from 3.44 percent in 1902 to 9.46 in 1927 and to 14.1 percent in 1934.

Fixed charges are practically independent of the load while operating expenses are definitely a function of the output. While superintendence, and to a lesser extent labor, cannot be varied as the load increases or decreases, other operating costs and particularly fuel depend upon the amount of power delivered. Thus in a hydraulic plant, which uses no fuel, the operating costs are practically the same whether the plant carries the maximum load or is standing idle; accordingly, any water which is allowed to pass over the spillway without producing power is a loss. The operating costs in the case of fuel-burning plants are a major item in the cost of power and the economies produced in these plants merit special consideration.

Stationary Steam Power Plants.—Our large coal reserves and the efficiency of the steam prime mover indicate that steam power plants will long remain a major factor in the production of mechanical power. In the stationary steam power plant the fixed charges have been going up during recent years while the operating expenses have been going down; yet better engineering has greatly reduced the actual cost per unit of power output at the point of delivery from the power plant.

The stationary steam power plant may be a central generating station or an isolated plant. It may be used to generate electricity for power and light as its main function, or steam heat, or electricity for transportation, or steam, electricity, compressed air, and other services for some industry. Local generation of power in small units is rapidly disappearing in the more thickly populated sections and greater use is being made of power purchased from central stations. The past 22 years and particularly those from 1918 to 1930 have been marked, not only by the growth in the amount of mechanical power used, but also in the economy of power production. The best steam-electric power plants are generating, at present, a kilowatt-hour on less than 1 pound of coal as compared with an average of 3⅓ pounds in 1918, 5 pounds in 1900 and about 10 pounds of coal in 1880.

Improved plant economy has been secured by utilizing steam at higher pressures and temperatures, by equipment designs to suit the fuel available, by economical fuel-handling methods, by clean feedwater at high temperature, by boiler surfaces free from soot and scale, by boiler settings and baffles free from leaks, by properly covered piping and other equipment which loses heat by radiation, by full utilization of live and exhaust steam, by adequate instruments for the purpose of keeping a careful check on plant-operating conditions, and by a general improvement in plant-operating technique.

In 1880 the steam pressure commonly used was 70 pounds per square inch, the steam being saturated—that is, the steam contained evaporated droplets of water. At the beginning of the present century very few stationary plants used superheated steam and the majority operated at steam pressures of 150 pounds per square inch or less. In 1918 the leading and largest electric central stations were operating with steam pressures of 300 pounds per square inch, at steam temperatures of about 650° Fahrenheit, and required fuel containing about 18,500 British Thermal Units (B. t. u.) per kilowatt-hour of net station output, when operating at about 60 percent load factor. The term "load factor" is the ratio of the average load to maximum or peak demand. In 1923 a few plants were operating at 350 pounds per square inch steam pressure and some were being constructed for pressures of 400 to 550 pounds per square inch at the boiler. At present there are numerous power plants, industrial as well as public utility, which use steam at pressures of 400 to 1,400 pounds per square inch, with steam temperatures of 750° to 850°[14] Fahrenheit, and which require only about 12,500 B. t. u. per kilowatt-hour of net station output. Binary plants, using mercury vapor and steam as the two fluids, are producing a kilowatt-hour for about 9,000 B. t. u. One industrial plant in this country is operating at steam pressures of about 1,800 pounds per square inch. Investigations are under way at pressures of 2,000 to 4,000 pounds per square inch and at temperatures in excess of 1,000° Fahrenheit.

High steam pressures and temperatures are particularly advantageous for industrial plants where use can be made of exhaust or bled steam for manufacturing operations in connection with stills, cooking kettles, dry kilns, vulcanizers, water heaters, air heaters, and for other processes which require heat. The magazine Power, in its fiftieth anniversary number in June 1934, lists six industrial plants of the United

[14] A new turbo-generator is now being built in this country to operate at a steam temperature of 929° Fahrenheit.

States which operate at pressures of 700 to 1,840 pounds per square inch, 10 at 500 to 699, and 131 at pressures varying from 300 to 499 pounds per square inch. In the same issue 10 central electric stations are reported to be operating at boiler pressures of 1,200 pounds per square inch or higher, 16 at 500 to 700, and 43 at pressures varying from 400 to 500 pounds per square inch. In the last group of electric generating stations 34 are privately owned and 9 are municipal plants.

The main objectives to be sought in a power plant are reliability of operation and cheap power. The plant must be dependable and commercially efficient to justify its existence.

The load factor, or use factor of a station, influences its design. The daily load factor and the form of load curve affect plant operating expenses. The annual load factor determines to a considerable extent the investment; thus a high annual load factor warrants greater expenditures for machinery to insure high-power plant efficiency. Base power loads are being carried by the most up-to-date and most efficient plants, while the older and less economical generating stations are reserved for peak load or emergency service. Progress in base load plant design has been so rapid during recent years that it is often practicable to change a plant after only a few years use from base load to peak load service.

In the case of large users, fuel specifications are found desirable in order to safeguard the interests of the purchaser while enabling the coal dealer to market fuels which are little used at present. The grade and size of fuel required depends upon the equipment used.

Adequate fuel storage is not only a protection against emergency plant shut downs, but flattens out the demand curve at the mines and upon the transportation systems.

The design of a power plant should be fitted to the fuel which can be obtained to best advantage. Smokeless and efficient combustion can be secured with any fuel if the fuel burning equipment is properly designed.

Hand firing of boiler furnaces for power generation is now seldom used and some form of mechanical firing, such as stoker or powdered fuel equipment is found even in small power plants.

The perfection of powdered or pulverized coal equipment and of stokers capable of handling widely different varieties of coal with considerable success has served to make steam plant operation more independent of the coal market.

Well designed stoker and pulverized coal installations give equally good results and the difference in the cost of these two types of installations is small for large power plants. The stoker is preferable and cheaper for very small plants.

Modern steam generators, commonly called boilers, are distinctive because of their high capacities or ratings which are made possible through improved water-cooled furnace design. The furnaces of large power plants use no firebrick lining but are provided with all metal water-cooled walls which represent the most effective part of the entire steam generating equipment. The heating surface of modern boilers, expressed in square feet, is from 8 to 14 times greater than those built in 1900. The rate of evaporation of water per hour in a steam generator has changed from 10,000 pounds in 1880 to 60,000 in 1910, to 300,000 in 1920, and to more than $1\frac{1}{4}$ million pounds in 1935. High capacity involves lower investment costs. Steam generator efficiencies have increased from 65 in 1900 to 85 or even 90 in 1935. To make high rates of combustion possible, induced and forced draft fans are a necessity. In general, modern high pressure and high temperature steam generators of high ratings are less expensive per unit capacity than the old types of low pressure boilers.

The steam turbine is the most important prime mover for the generation of electricity, as it operates at practically uniform speed, occupies very much less space than a reciprocating steam engine, can be built in very large sizes at low cost, and is very economical in steam consumption. The development of power from fuels by means of steam has been continually in the direction of more powerful prime movers, as operating costs decrease with the size of steam units. With the steam engine there is a limit to the size of a unit beyond which it is impractical to go. The maximum practical size of a reciprocating steam engine for stationary power plants is less than 10,000 kilowatts, while steam turbines of capacities of 160,000 to 212,000 kilowatts are now in operation in central electric stations. The modern steam turbine is highly economical and is used exclusively in large steam-electric plants. Besides the advantages mentioned, its high speed of rotation makes it more economical for driving electrical dynamos, the size and cost of dynamo-electric machinery decreasing as the speed increases. The steam turbine, because of the above-mentioned advantages, has made possible the modern large electric generating station and has also stimulated long-distance electric transmission of electricity.

The reciprocating steam engine, while limited in its size and not adaptable for large-scale electric generation, is advantageous for certain industrial and transportation uses on account of its fairly low speed and high starting torque. Reciprocating steam-engine speeds permit direct mechanical drive of tools and machinery which cannot be handled by steam

turbines without speed-reduction gearing. The steam-engine speed is easily controlled, and it lends itself to uses where variable speeds and loads must be handled, such as in steam locomotives. Its economy, when exhausting at atmospheric pressure or higher, is better than that of a steam turbine; thus the steam engine lends itself to certain industries where use can be made of exhaust steam for process work. In using exhaust steam from a steam engine, care must be taken to eliminate oil from the steam to prevent damage to piping, fittings, and equipment using exhaust steam.

The reliability of power supply depends upon the degree of availability or the percentage of time during which the equipment is available for use. Modern large power equipment has a degree of availability of 85 to 95 percent on an annual basis. The plants themselves provide 100-percent time service.

Large central generating stations require enormous quantities of cooling water for condensers as well as extensive facilities for receiving and storing coal. The necessity for an adequate supply of cooling water at low temperature practically restricts the location of large steam-electric plants to water sites.

The economy of old plants has been greatly increased during recent years by superposing upon available equipment, new machines which operate under higher steam pressures. An old plant in Detroit which produced a kilowatt-hour for 19,000 B. t. u. was rebuilt to use steam at 700 pounds per square inch and 825° Fahrenheit; this resulted in reducing the heat consumption per kilowatt-hour to 13,000 B. t. u.

Steam-electric plant economies for 1934, in B. t. u. per kilowatt-hour of net station output, at 60 percent load factor, are given in the 1936 Interim Report of the National Power Survey of the Federal Power Commission as: 28 percent of the plants had an economy better than 14,000 B. t. u.; 47.8 percent, between 14,000 and 18,000; 15 percent, between 18,000 and 22,000; 4.8 percent, between 22,000 and 25,000; 3.1 percent, 25,000 to 30,000; and only about 1 percent over 30,000 B. t. u.

Plant efficiency has improved greatly owing to the recognition of the importance of well-trained and experienced power-plant personnel. The fireman of 40 years ago has been replaced by a combustion engineer well versed in the fundamentals of science, and able to apply chemistry and physics to actual operating problems. In addition to improved personnel, power-plant operating technique has greatly benefited by automatic and semiautomatic control, by the development of heat-saving equipment in connection with the modern steam generator, and by the perfection of accurate meters and instruments.

Internal Combustion Engines.—While the United States has considerable oil and gas resources, it is nevertheless essentially a coal-producing country. Thus the internal-combustion engine in this country is not as important for stationary plant purposes as it is in certain other lands where coal is expensive.

One important advantage of the internal-combustion engine is that its economy is practically independent of its size. This is in contrast with the steam plant, the fuel economy of which increases with the size. The maximum fuel economy of an internal-combustion engine is reached in small units, while the economy of steam prime movers is at its maximum only in very large plants. Thus the internal-combustion engine, using oil or gas as fuel, is well adapted for small plants.

The internal-combustion type of prime mover involves low stand-by losses and, accordingly, it is useful for emergency, peak load, or other intermittent service in steam-electric plants; it has also some field as an auxiliary prime mover in small hydroelectric developments.

For large scale power production, as in electric-generating stations, the internal-combustion engine is not a competitor of the steam prime mover, except for auxiliary and emergency service, or in localities where fuel suited for internal-combustion engines can be obtained at a very low price. The steam power plant, in large units, has a thermal efficiency which compares very well with the Diesel type of prime mover, and offers additional advantages because of its lower first cost and greater reliability; furthermore the steam power plant uses coal, a cheap and widely available fuel in this country.

The gasoline engine is particularly suitable for automobiles, farm uses, and airplanes on account of the ease with which it is handled. In the case of trucks, busses, and tractors an oil fuel which is cheaper than gasoline is to be preferred.

Where cheap natural gas or industrial gas, such as blast furnace or byproduct coke-oven gas, is available at low cost, and no heating or process steam is required, the gas engine is an economical prime mover.

The gas engine using natural gas has an important place in gas and oil fields. About one-tenth of the present supply of gasoline comes from oil well or "casing head" gas from which it is recovered by the compression system. Thousands of these "casing head gas" recovery plants use gas-engine driven compressors. Gas engines are also used in connection with natural gas pipe-line installations.

Blast furnace gas engines in sizes up to 10,000 horsepower are in use in steel plants, but the predictions of the extensive use of this type of prime mover,

made 30 years ago, have not been realized on account of the progress made in steam-power plants.

Considerable attention has been devoted to the development of oil engines. In the latter years of the last century, a number of American gasoline engine builders attempted to develop a low-pressure engine which could be operated on the heavier and cheaper petroleum fuels. Several types of such engines have been in use, but the present trend is toward some form of Diesel engine, on account of its economy with low-grade fuel oil.

The Diesel engine has the highest thermal efficiency of any heat engine. The Diesel engine uses a lower grade oil than the low-pressure internal-combustion engines, and converts more than 30 percent of the heat of the fuel into work, as compared with only about 20 percent in the case of the ordinary gasoline or other low-pressure oil engine.

The number of Diesel engines in use has mounted steadily, as their refinements have improved fuel economy and increased reliability. In 1906 the total production of oil engines was less than 100,000 horsepower with the Diesel type only a small part of the total.

Diesel Power in February 1936 reports that the new installations of Diesel engines during 1935 totaled 1,201,123 horsepower as compared with 750,000 in 1934 and with 450,000 horsepower in 1928, which was the top year in Diesel power before the depression. A total of 8,077,123 horsepower of Diesel engines was sold in the United States up to January 1, 1936. Lightweight Diesel engine propelled trains have focused public attention upon this type of prime mover for transportation. Up to December 1934, the total sales of Diesel engines in this country were 6,876,696 horsepower; of this 16.5 percent was sold for marine use, 15 percent for general industry, 8.5 percent for privately owned public utilities, 6.5 percent to municipal power stations, and 2.5 percent to railroads. The largest sales of Diesel engines during 1935 included the following: Tractors, 450,000 horsepower; stationary power plants, 265,000 horsepower; contractors, 110,000 horsepower; marine, 95,000 horsepower; trucks, 75,000 horsepower; and railroads only 25,000 horsepower.

All internal-combustion prime movers suffer by comparison with steam prime movers whenever the load factor of the plant is low; that is when the total output in horsepower per year is low in comparison with the total possible every day all day operation at full load. While the thermal efficiency of Diesel engines is somewhat better than that obtained in the largest and best steam-power plants, it cannot compete with the modern steam-turbine plant for central station use on account of its high initial cost, its limited size, the type of fuel it must use, and its inability to carry overloads.

Water Power and Steam Power.—Waterfalls are among the oldest source of energy. Water power was responsible for the growth of a number of the older manufacturing cities of the United States such as Paterson, N. J., Lowell, Mass., and Pawtucket, R. I. It must not be inferred, however, that the availability of a waterfall, where water runs to waste, if not used, means a cheap source of power. Water power lacks reliability, as it is affected by meteorological conditions, dry seasons, floods, ice in the water supply, and mechanical and electrical interferences with transmission lines connecting the power with distant markets. The water-power plant involves geographic restrictions, as waterfalls of importance are usually located far from power-consuming areas. However, water power is next in importance to steam in connection with large-scale power generation in stationary power plants.

Water turbines are built in capacities up to 115,000 horsepower in a single unit, and to efficiencies of about 94 percent. In fact, no prime mover transforms energy into useful power so efficiently as does the modern hydraulic turbine. However, while the hydraulic turbine is a most efficient prime mover, the water power plant involves greater capital risks than is the case with fuel-burning plants. The fixed charges of a hydroelectric plant are usually high as compared with a steam-electric plant; the investment for dams, water storage, long-distance transmission lines to market, and emergency power reserves involve large investment costs. The annual distribution of rainfall and run-off cannot be controlled, and because of this, great extremes of high water and low water occur, making possible the utilization of only a portion of the potential power in a waterfall. Thus hydroelectric stations must use steam or internal-combustion engine stations for emergencies, peak loads, low-water periods, and during floods. Through interconnection of hydroelectric plants and their interspersion with steam plants, the difference in time of seasonal flows of different drainage areas has been taken advantage of and the reliability of service improved.

Water-power plants are usually more expensive than steam plants for equally good service if steam or internal-combustion engine reserves are included in the cost estimates. Ordinarily hydroelectric power plants will involve a cost in excess of $150 per kilowatt capacity as compared with $75 to $125 for steam-electric plants.

F. F. Fowle, consulting engineer of Chicago, in his paper on the Nation's power supply, previously quoted, states that under ordinary conditions a steam plant will deliver current at the power-plant bus at 4 mills

per kilowatt-hour as compared with 6.3 mills for a hydroelectric plant. These figures include fixed charges and operating expenses, $85 per kilowatt installed capacity having been assumed as representative for the steam plant and $250 for the hydro plant. When a hydro plant is coordinated with a steam plant the unit costs are reduced. In general, however, fixed charges and reliability insurance are items which should be given major consideration in comparing steam-electric and hydroelectric plants.

Among the disadvantages of the steam plant as compared with the water plant is the fact that turbines and steam generators cannot be placed in service on short notice. Water turbines can be started up and shut down almost instantly without waste of energy provided enough water is available to operate them. Then water storage in a reservoir just above a hydroelectric plant can be used advantageously to take care of load fluctuations. Hydro plants supplemental to steam plants are practical in numerous cases where steam is used for base-load service and hydro prime movers are available for peak or emergency conditions.

In many localities, however, absence of fuel cost does not make up for high fixed charges and low reliability of water power. The high efficiency and low fixed charges now possible in large fuel-burning plants, place hydroelectric developments at a disadvantage in most sections of the United States if low power cost is the objective. Water-power plants, due to their high fixed cost, depend even more than do fuel-burning plants upon a high use factor or load factor.

Isolated Industrial Plants and Central Station Service.—Manufacturing industries are spending large sums for power, heat, and light. The United States census of manufactures showed that, for the year 1927, the total cost of all power and fuel was about 7 percent of the "value added by manufacture" and about 3 percent of the total value of the products. Thus the cost of power to industry is nearly as great as most manufacturing plants pay in dividends during normal times. Accordingly, the power and heat supply of an industry merits careful study.

Until 1910 there were numerous isolated power plants installed in factories and public buildings. Most of these were inefficient, but with cheap coal this was not important. Better and cheaper service from electric-generating stations and higher fuel prices were responsible for the shut-down of many of the less efficient plants in favor of purchased power. During recent years there has been a marked revival in the construction of isolated plants in certain process industries. About one-half of the power used by industry is purchased, and the installed capacity of industrial power plants is less than one-half of that of the electric central stations of this country. It must be recognized, however, that the kilowatts of installed capacity and the kilowatt-hour output, while practical measures for electric-generating capacity and output of an electric public utility, are not the proper measures of comparison for industrial plants, as the latter plants use steam, water, compressed air, and refrigeration as well as electricity; in many such plants the steam-generating capacity is several times greater than that needed for the generation of electricity.

The future growth of isolated industrial power plants will depend upon the balance between power and heat requirements of specific industries, the relative design and operating standards of industrial and utility plants, and the willingness of industries and utilities to cooperate through an interchange of power and steam. Local conditions determine the choice between an isolated plant and purchased power. The steam and electric demands of the industry, the reliability of service furnished by the central station, rates for steam and electricity, and other factors must be considered. The cost of producing power in industrial plants having need for large quantities of exhaust steam is, in many cases, so small, particularly if high boiler pressures are used, that generally no central electric-generating station can compete. The availability of high-pressure bleeder and back-pressure steam turbines in small sizes has made it possible for certain industrial plants to obtain large quantities of power from process steam at low cost.

An industry is usually in a position to generate its own power cheaply if it has a large supply of waste heat at high temperature or where industrial wastes can be used for fuel, as is often the case in woodworking factories and byproduct coke-oven plants. Maximum heat utilization is possible in the case of noncondensing prime movers; thus where an industry can find sufficient use for exhaust steam during the major portion of the year, and where low-pressure steam in large quantities is required for driving special equipment or for process work, an industry will usually do well to consider the installation of an isolated plant for its own use. Industries may also justify their own plants, irrespective of their low-pressure steam requirements, if they use much power, have a good load factor, and are located so that they have a plentiful supply of water for condensing purposes.

In industries in which it is practical to coordinate the consumption of steam, heat, water, and power, an isolated plant makes possible the most efficient use of high-pressure steam, with the consequent economies in power generation. However, while only about 5,000 B. t. u. additional heat is required to produce a

kilowatt-hour from steam used for process work, an industry should not consider the installation of its own power plant unless about one-fourth of its power needs can be generated as a byproduct of the heat supply for other purposes.

Where an industry has available steam or power beyond its own requirements it may advantageously consider the sale of such excess steam or electricity to other industries or to a public utility in its own locality. There are some industries, such as sulphur mining plants, which have large steam requirements but use little electric power. Then there are industries which have fuels in large quantities as byproducts: examples of this are steel mills, large sawmills, and municipal garbage incinerators. An electric central station, private or municipal, may then act as a market for the excess power from such sources.

Ordinarily electric public utilities have been interested only in selling electricity. Making it possible for a manufacturing plant to buy steam from an electric central station, as well as electricity, has often helped utilities to retain their large electric customers and to build up a new source of revenue through the sale of steam. Utilities should be ready to sell steam as well as electricity. By so doing the duplication of power-generating facilities in isolated plants could often be prevented.

In one case, a central station runs a high-pressure steam line to an industry: the industry utilizes this steam for manufacturing as well as for the generation of current on its own premises, and sells current in excess of its needs back to the electric central station. Certain industries can make particularly advantageous use of high-pressure steam and in such cases pooling with the utility is advantageous to both.

W. A. Hanley, director of engineering for the Eli Lilly Co. of Indianapolis, stated at the midwest power conference in Chicago in April 1936: "Without fear of contradiction I can say that there are a few industrial concerns and not many large hotels, stores, and office buildings who can afford to build their own boiler plants if they are located within 2 miles of a modern central station and if both parties be willing to divide the saving made possible by a reciprocal arrangement."

Supplying steam to industries, combined with a general central heating service, has been advocated. The district heating industry in several of the large cities of this country has demonstrated that steam lines are reliable, have a long life, and do not lose an excessive amount of heat when properly insulated. Installations of central heating lines a mile long and longer have been used advantageously.

When industries and utilities consider an interchange there are numerous factors which must be taken into account to safeguard the interests of both parties. The availability of excess power, load, and steam-demand curves of an industry, reliability of service from the industrial power plant, attitude of State utility commissions to rates proposed for the interchange, and similar matters must be considered. Clear understanding and definite cooperation of all parties involved are major essentials in an interchange of electric power and steam between industries and utilities.

Small industries ordinarily find it advantageous to purchase light and power from a public utility, installing low-pressure steam boilers for heating and process work, as the operating standards in small industries are usually low. Industries planning to build their own power plants must be willing to pay for superior engineering design, high-grade equipment, and capable operating personnel if they expect to generate power and steam profitably.

The Social Significance of Power

The Age of Mechanical Power.—Man is supposed to have passed through several epochs in the march of progress from savagery to civilization. The dawn of each of these epochs was characterized by new inventions or discoveries which increased his comfort, his safety, his intelligence, or his well-being. The present epoch is called the "Age of Mechanical Power", and is considered by many as more important than the epochs which followed the introduction of the use of fire, the domestication of animals, the cultivation of fruits and grains, the discovery of iron, or even the invention of the printing press. Until the dawn of the "Age of Mechanical Power", man's capacity for work and production was limited by his own strength plus that of domestic animals. Mechanical power in the short interval of a little more than a century, by transferring reliance from animate to inanimate energy, has revolutionized the whole environment of human life by enabling man to utilize the energy and materials of his environment more effectively. Past civilizations rested upon human slavery; our times are dependent upon mechanical power and energy resources. In the finest civilizations of the past, leisure was afforded to the few by the hard labor of many human slaves. Human slavery has given place in modern civilized lands to mechanical power, which has placed a new valuation upon human life.

Mechanical power, enabling man to do more work, and to do it in less time and more easily, has enabled the people of this country to develop in directions other than securing a mere existence; has released youth from labor and made possible for them universal education, and has benefited the whole population by providing them with new conveniences and luxuries

in addition to food and shelter. In this "Age of Mechanical Power", a premium is placed upon the superiority of mind over muscle, and human slavery is not only illegal but it is absolutely impractical because of the high cost of human labor compared with mechanical power. A mechanical horsepower, costing $20 to $50 per year, substitutes for 10 to 15 human slaves; furthermore, a machine can operate continuously day after day whereas a slave cannot. Power means progress, relieving man of drudgery and enabling him to make the best use of his opportunities. Men now direct machinery by which work is performed.

Civilized people of today are dependent upon mechanical power and power-driven machinery for the furniture and furnishings of their homes; for the clothes, hats, and shoes they wear; for the materials which enter into building their shelters; for their systems of transportation and modes of communication; in fact, for the material content of the present civilization. The very food on the table is drawn from farm, forest, and stream by highly developed systems of transportation, preserved by machine processes, and prepared for use by gas or electricity, all of which depend upon mechanical power. Manufacturing, mining, communication, transportation, and other fields of productive activity have been advanced by mechanical power shortening the time necessary to achieve results.

Mechanical Power and the Industrial Revolution.—Mechanical power is the result of the efforts of many minds, some dating back more than 2,000 years. Various mechanisms and machines were invented by man centuries ago to aid him in his labors; these, however, were insufficient to free him from drudgery until 1769, when James Watt succeeded in bringing out a practical prime mover, embodying nearly all the principles that were afterward perfected in the modern steam engine. Engines were used for about 65 years before Watt, for pumping water from mines; while these were called steam engines, they were actually atmospheric engines in that they used steam chiefly to produce a vacuum below the piston. The necessity of finding better means for pumping water out of mines and particularly out of coal mines was mainly responsible for Watt's contribution which started the wheels of the world in motion. By demonstrating how to turn heat into mechanical work effectively, Watt helped to create an improved civilization by stimulating through his own work all forms of invention.

Watt extended man's capacity for work through the use of power and made industrial development possible. England in 1769 was largely rural, nearly one-half of its 8½ million people lived in the country. Commerce was concerned only with the bare necessities of life. The tools of industry were simple and were usually operated manually by their owners. Watt's invention was largely responsible for replacing domestic manufacture by mass production, and changing England from an agricultural to an industrial country. The introduction of mechanical power helped to change the nature of production from the individual worker system to the factory system, at the same time transferring the skill from the worker to the machine.

To what extent was the steam engine responsible for the industrial revolution in England (1760 to 1840) which has contributed so largely to our own present industrial problems?

The industrial revolution was under way about a decade before Watt patented the improved steam engine. As late as 1790 only about five steam engines were in use in both England and Scotland. The early textile mills were along the water courses of Yorkshire and Lancashire and were very slow in substituting steam power for their water wheels. Furthermore, it should be realized that exploitations of labor existed long before Watt, when coal from English mines was carried on the backs of women and children.

Watt's work was a factor in, but did not initiate the industrial revolution. The development of the steam engine, the invention of different methods of transmitting power and the application of the steam engine to transportation gave a great impetus to progress. Mechanical power makes possible greater human happiness, but does not insure it. Humanity has been enriched and benefitted by the work of Watt, of whom the great poet Wordsworth said: "I look upon him as perhaps the most extraordinary man that this country has produced." However, neither Watt nor his invention is responsible for the selfishness and brutality which characterized the introduction of the "factory system" in England. The industrial revolution during the first century of industrialization, and the frequent economic depressions which have paralleled the increased use of power, are not particularly creditable chapters in our history, but the evils which we have experienced during the "age of power" are not an indictment of power itself but of the inability of men to use it wisely.

Power and Human Welfare.—Little, if any, improvement was made in the material condition of the great masses of people during the thousands of years of recorded history before the nineteenth century. Even at the end of the eighteenth century the necessities of life were produced by hand labor; people lived off their country's obvious supplies and were concerned mainly with the production of raw materials—of grains and minerals—of lumber, wool, and

some cotton. In the art of transmitting intelligence, the people of George Washington's time had made practically no improvements as compared with the fire and smoke signaling methods of the ancient civilizations. Transportation facilities, even as late as 1820, were scarcely more adequate than those in use 2,000 years before; on land, people were hauled by man or beast, and on water, dependence was placed upon the muscles of the oarsmen or upon the vagaries of the wind.

Mechanical power has transformed the world during the past century. Compare the conditions at the time of Watt with those at the end of 1935, when domestic consumption of electricity was about 14 billion kilowatt-hours; when over 7¼ million electric refrigerators, 10¼ million vacuum cleaners, 10½ million electric washing machines, 10½ million electric toasters, 20½ million electric irons, and 22 million radios were in use in the American home; when over 22½ million automobiles were licensed in this country; and when other comforts and luxuries were made available to all by power and power-driven machines.

Modern industrial activity, mining, transportation, communication, and illumination are absolutely dependent upon mechanical power. It also plays a major part in all industries, including agriculture, mining, manufacturing, transportation, and communication, which are indispensable to national security and happy living. Mechanical power must be used for the manufacture and for the distribution of the necessities and luxuries demanded by modern times.

Mechanical power has benefited the farmer as well as the city dweller. Power has released for sale crops formerly used for feeding animals, and has increased the output per farm worker by the mechanization of farm operations. Extensive use of power and of power-driven machinery has made it possible for one farm worker to take care of much greater acreage; while his hours of labor, like those of the city dweller, have been greatly reduced, and much of the monotony and drudgery of his labor have been eliminated. Transportation has created new markets for farm products. The telegraph, telephone, and radio have furnished the farmer with price information. In fact, mechanical power has changed agriculture from subsistence farming to a business enterprise.

Our present, power-propelled, transportation facilities are making our raw materials and our manufactured products more accessible; are shortening open spaces; are improving life in many remote places; are bringing communities within social and commercial range of each other; and are enabling us to enjoy the products of far-distant localities. Next to the school, the automobile more than any other factor has practically obliterated the difference in the characterization between the urban and rural peoples of the United States of America.

Power makes possible an economy of abundance by increasing production and by cheapening the products of industry. Power-driven machinery lowers prices, and at the same time increases wages and profits. More power and more power-driven machinery will go on providing new comforts, new opportunities, and new luxuries to the masses of people. R. E. Flanders, in his book entitled Platform for America makes the following pertinent observations:

> Why speak of over-production when we have never had a decent general standard of living in this country? Why speak of technological unemployment when it is on technology alone that we can found our hopes for the higher standard of the future? Why speak of over investment when an adequate provision of goods and services to the mass of our fellow citizens requires larger and more efficient production facilities than we have ever dreamed of?

Power makes available more and more goods at lower and lower prices, relative to the people's income.

Power is a great force of democracy, as its benefits are widespread and available to all the people, to the poor and rich alike. Power, by reducing production costs, has brought within the reach of all but the very poorest people conveniences of living which were formerly not even enjoyed by the richest.

Present estimates indicate that the power available per capita in the United States is at least 10 horsepower, when all uses are considered, or about 40 horsepower for each of our 30 million families, the equivalent of at least 400 human slaves and yet as Dr. Hirshfeld has said "not a single human being is sold at the auction block." The available mechanical power has increased from 70 million horsepower in 1900 to over 1 billion in 1935. During the same 35 years the power used on the farms has increased about eight times. This enormous amount of power at our command in this country has resulted in a standard of living unknown at any other time in the world's history. Power has been of particular benefit to people of low income who are now better off, in a material sense, than ever before in the history of the world.

Power is indispensable to industry and to community life; interruption of power supply throws men out of production and deprives us of our customary modes of transportation and communication, as well as of illumination and many of the other necessities of modern living.

Power and Industry.—England's preeminence among the manufacturing countries of the world during the first half of the nineteenth century is attributed to its early appreciation of the potential value of power-driven machinery. At the same time it is of interest that Lloyd George in his 1923 report had

recommended the complete industrial rehabilitation of Great Britain, pointing out that the industrial centers of the United States of America used two and one-half times more power per capita than did England and that the real wages of the American workers are greater in about the same proportion. The more power at a workman's disposal, Lloyd George concluded, the greater is his output and the higher his wage; while at the same time, the lower will be the cost and the market price of the goods he manufactures.

Over 20 million horsepower are available to turn the wheels of American industries. From 1899 to 1925 the number of wage earners in the United States nearly doubled, while the power of the machinery installed in industry has increased over three and one-half times, or from 2.1 horsepower per factory worker in 1899 to 4.67 in 1927; the present figure is in excess of 5 horsepower of power-driven machinery per worker. The real wage levels of industrialized lands are closely related to the power per wage earner.

Mechanical power underlies the whole mass-production system of today with low prices for manufactured articles. Hand-operated machinery is rare in modern industry. L. P. Alford, in his treatise Laws of Management (1928), states that the productivity of the industrial worker has increased 40 percent from 1919 to 1925 and that the greatest productivity has taken place in industries which have continued to expand their power uses, such as the automobile industry which increased its output during that period 172 percent. In this connection it is interesting to know that in the period from 1870 to 1930, the population of this country multiplied by three, while the number gainfully employed multiplied by nearly four.

Power-driven machinery made it possible for old industries to expand and for new enterprises to be undertaken, creating new fields for employment. The 18 major industries of today which employ directly and indirectly about 25 percent of those gainfully employed in this country were absolutely unknown in 1870.

While mechanical power has been instrumental in separating the worker from his tools and agriculture from industry, it has definitely created more callings and more employment than it has eliminated. Science and engineering, aided by mechanical power, have been responsible for the creation during the past 70 years, where nothing was before, of such giant industries as those which manufacture automobiles, radios, typewriters, talking machines, airplanes, electric refrigerators, air-conditioning equipment and telephones, as well as new utilities which are concerned with electric communication, electric transportation, and electric light and power. These are creations, not mere developments. These have not displaced labor, but have added new opportunities for profitable employment and happy careers for millions of people. Power-driven machines have created in the past and will create in the future jobs which would not have existed without them.

Discussion of Trends

In viewing the status of mechanical power in the United States of America the following conclusions may be drawn:

A tremendous amount of power is available for use. A conservative estimate would place the total power at our disposal in this country at 1¼ billion horsepower.

Our civilization rests upon the foundation of power-driven machines. Mechanical power having changed us from a nation of individuals to a people made up of interdependent groups, has increased our social responsibility. C. F. Hirshfeld has stated that—

> It would appear that our young giant Power even in his adolescence has already set men free in a most astounding fashion—He has given to the masses new opportunities and has lifted the burden of the day's work from the shoulders of many. He has opened up vistas of progress, of accomplishment, of improvement, of real worth. As power more and more liberates us from the doing of the more lowly and time-consuming things having to do with mere living, we shall have time to live in a fuller and more satisfying way.

Mechanical power has definitely contributed to man's upward progress. In order that humanity at large may gain the greatest benefit from the age of mechanical power, sustained and clear thinking of many minds will be needed. The future power policy of this country must be considered upon a fact-finding basis, without prejudice or passion, and action must be taken slowly and deliberately so as not to hinder progress.

Has too much attention been given to generation or production of power and too little to other factors which make up the cost of power? The cost of power at the switchboard in the case of modern fuel-burning plants varies from 4 to 6 mills per kilowatt-hour; but complicated problems in the transmission, distribution, and marketing involve fixed and other costs, the reduction of which require careful research and unbiased study. The solution of such problems from both angles requires a thorough knowledge of the technical phases and the economic factors, as well as a keen appreciation of the social implications involved.

The significance of rural electrification has not been fully analyzed. Can it be greatly extended if those receiving the benefit are actually expected to pay its cost? What will be the effect of extensive rural electrification upon employment, and will it result in cheaper farm products and in greater profit to the

farmer? Will extensive rural electrification change population trends and, if so, in what direction? Present practice indicates that it is difficult to render self-supporting rural electric service at a cost which the prospective customer is willing and able to pay.

Over what maximum distances is it practical to haul coal and oil, or pipe oil and gas, or transmit electricity, so as to utilize our resources and developments most economically from the social as well as the financial standpoint? Calculations show that, at present mid-western freight rates, it is as cheap to haul coal 900 miles to the point of power production as it is to transmit power electrically a distance of only 200 miles.[15] Accurate data for such comparisons are lacking, although it is quite evident that it is uneconomical to transmit alternating current electricity over great distances. Furthermore, coal can be stored at the place of use while electricity cannot.

In the past 35 years the output of the workers of this country has greatly increased as the power to supplement their labor has more than doubled. This has opened new opportunities for large numbers through services and special needs brought about by the new demands of old industries and by the development of new industries. At the same time more power has permitted greater human culture, more comforts, and, in general, a higher standard of living for all. There is need, however, for data which will give an accurate picture of the effect of mechanical power and power-driven machinery upon employment.

Is mechanical power of sufficient importance to influence population shifts? The above questions and many others indicate the need for careful research into the social implications of power by those who know most of the techniques involved in the power industry.

To insure more general well-being in the future, more and more power should be made available at low cost, and to that end the following factors should be given consideration:

Power Developments of Minor Consequences.—The utilization of tides for power production is of questionable practicability, as is also the system proposed to develop power by taking advantage of the difference of the temperature of the surface water and that of the ocean depths. Both of these schemes involve high fixed charges and cannot be considered in a land of low-fuel costs.

Wind will remain of minor consequence as a source of power in this country.

The utilization of the heat of the earth itself is a possibility, but not one for the immediate future.

The suggestions made to utilize thunderstorms are of remote practicability.

Some progress has been made and more is likely to follow in the use of solar energy. Thermal plants utilizing the sun's rays have been used to some extent; but on account of their low output in relation to their cost and bulk, such prime movers do not offer any promise of practicability in the near future.

Photoelectric or photochemical effects have been suggested for utilizing the direct rays of the sun, but these methods are also still highly speculative.

The discovery and use of catalyzers in chemical processes may influence power production, but not in the near future.

The Van de Graf frictional generator is a major scientific development, but will hardly influence, in the near future, power generation and transmission. The transmission of power by radio is also remote from practical utilization.

Greater Use of Electricity.—Electricity has multiplied the uses of mechanical power. It appears, however, that neither the home nor industry is making full use of electricity. Apparently less than two-thirds of the urban population live in homes wired for electricity and less than one-half of those wired use electric current only for lights, doorbells, and flatiron. As time goes on and development expenses have been met, one can predict much lower prices for electric appliances, and the consequent greater use of electricity in the home for cooking, baking, water heating, laundry service, and many other uses; it is doubtful as to whether it is reasonable to expect electricity to be cheap enough in the near future to make possible its use for household heating, except during certain seasons of the year and in special localities. The devices which consume large amounts of energy are those which produce heat. Thus a large use of electricity for heating water in homes would greatly increase the load of central-electric stations, and would result in lower costs to the user of electricity.

We are on the brink of new developments in television, air conditioning, electric typewriters, and many other devices which will definitely increase the electric load on the power-generating stations of the country. Air conditioning in particular is bound to be extended in the very near future to the home as well as to the office and factory. As the discovery of fire has enabled civilization to reach into the colder areas so will air conditioning make the tropical sections of the world more habitable. Air-conditioning equipment will involve large extensions in the generating capacities of electric stations. Air conditioning may be cheapened by the use of steam to heat and humidify the air in the winter, and to cool and dehumidify the air in the summer. One of the limiting factors to the

[15] Engineering Economics in the National Power Picture. Printed and distributed by the Western Society of Engineers, Chicago, April 22, 1936.

wide extension of present air-conditioning systems is the inadequate supply of water in many of our thickly populated centers.

The greatly increased use of electricity in the home (rural as well as urban) brings to mind the question as to whether this will be accompanied by a return of home industries. As far as can be ascertained, this will not be very extensive by reason of the fixed charges involved in power-driven machinery. It is reasonable to suppose that laundry work, cooking, and baking may increase in the home as inexpensive appliances and cheap power become available. The cleaning of rugs, furniture, and walls by the householder may also increase. It is unlikely, however, that the home will install expensive equipment for the manufacture of cloth, clothing, shoes, or furniture to meet its small needs. Low cost power will encourage greater use of electricity in the home for transportation; and in industry, for a great variety of purposes—such as welding, heating, driving tools, and for various electronic devices.

As American industry grows and as improved manufacturing processes are being developed there is bound to be a constantly increased use of electricity by industry. The percentage of electrified tools and machines of industry is bound to increase. Electronics, photoelectric cells, and relays will be expanding the demand for power in industries.

Fuels in Power Development of the Future.—There seems to be no need for special concern about the resources available in this country to produce power by the present methods. Even with a greatly increased use of power, which is bound to come in the near future, our resources are adequate for centuries to come, if we continue to rely mainly upon coal-burning plants.

Our immediate problem is to make power available at low cost without exhausting certain resources which are limited. Thus it seems undesirable to use petroleum as fuel for steam generation or even for household heating in regions where coal is available, as petroleum and its distillates are so important for lubrication purposes and for motor vehicle propulsion. Up to date no suitable substitutes are available for gasoline as a fuel for automobiles and airplanes. Mr. Willard E. Herring in the report of the National Resources Board dated December 1, 1934, states that petroleum "is of paramount importance to our national welfare and security. The automobile, airplane, and oil burning ships have become modern necessities. Liquid fuel to propel them and oil for their lubrication are indispensable. Consumers have an investment of 15 billion dollars in automobiles and a 12 billion dollar industry has been built up for the production, refining, and marketing of petroleum and its products." Certain heavier petroleum products should be reserved for lubricants and for use in Diesel engines. The use of crude oil for power or for household heating should be discouraged.

Natural gas is also inherently too valuable to be used as fuel for household heating and for industrial purposes in regions where coal is available at low cost, and its use as a fuel for steam generation should also be discouraged. Natural gas can be converted into solvents, acids, and other chemicals of greater significance than the mere fuel value of natural gas. Petroleum and natural gas are fuels which are not replaceable, and should not be used in places where a widely available fuel, such as coal is readily applicable.

As the cost of manufacturing alcohol is decreased, in comparison to petroleum, through cheaper raw materials and greater efficiency in production, this fuel will become important for the propulsion of motor vehicles.

Hydroelectric Plants.—The hydroelectric and steam-electric plants are complementary sources of power. There is need for accurate studies to develop the proper proportion of hydro to steam plants in different sections of the country for the most economical power generation. Present low costs of steam plants necessitate discrimination in developing water power sites.

Hydroelectric plants are practical where good water sites are available, not too far from load centers, with well sustained continuous water flow, or with water storage which can be developed at low cost.

In most regions of this country the hydroelectric plant should be considered as complementary to the steam power plant rather than the main power source. Water power can supply power in certain localities during peak load periods at low cost per kilowatt-hour.

Lower Power Production Costs.—Improvements in plant design and in operating technique have lowered greatly the cost of generating power in steam-electric plants, so that modern installation can produce power at the switchboard at a cost of only from 4 to 6 mills per kilowatt-hour. There seems to be little room for lowering the fuel consumption per unit of output in steam power plants, without resorting to new cycles.

Mercury-steam binary cycles give a plant economy of 9,500 B. t. u. per kilowatt-hour as compared with about 12,200 B. t. u. for the most efficient steam plants. It is unlikely, however, that this type of binary cycle is the final solution. Other types of binary cycles such as steam-ammonia have been proposed. It is possible that there may be other combinations of fluids capable of yielding practical results in improving the thermal efficiency through the use of new binary cycles.

To reduce the cost of power at the switchboard the greatest possibilities seem to lie in reducing fixed

charges by simplifying designs, cheapening power plant building construction and by locating out of doors more and more of the equipment now generally housed. Lowering fixed charges should be accompanied by improvements in operating technique and by constant research for the purpose of making better use of higher temperatures and high pressures in steam cycles, and for building better and more reliable power plant equipment.

Mine-mouth power plants are practical only in rare instances, as a modern steam-electric plant of 150,000 kilowatts capacity requires as much water for cooling purposes as does a city of about a million inhabitants. Furthermore, mine-mouth location will ordinarily involve electric transmission costs greater than freight charges on fuel; at the same time long transmission lines reduce reliability of service.

As to policies with reference to new plants, either fuel burning or hydro plants, or a combination of the two, are justified when present facilities are inadequate or cannot be extended at a cost less than that of a new plant. Competing plants in one city are usually unwise for economical reasons.

Improved electric power transmission methods will no doubt be an important factor in decentralizing of industries; industries will locate more and more in communities where the worker can live more cheaply and better than in the crowded urban centers.

The increased use of electricity generated in large plants and the reduction in the number of small isolated and inefficient plants will result in cleaner cities.

Power for Transportation.—For many years in the future, the steam locomotive, which will be greatly improved, will remain the main source of power for railways. Its thermal efficiency will be greatly increased by improvements in the locomotive boiler and is appurtenances, and in the method of steam distribution. Preheated air, now commonly used in electric generating stations, may be used advantageously in locomotives. Improved types of steam generators, probably of the water-tube type, may gradually replace present equipment. Pulverized fuel, burned successfully in stationary plants, may well be considered for use in locomotives where the types of fuel available make pulverized fuel preferable to stokers. Present locomotives carry much dead weight, which cannot be fully utilized for traction. The next few years will see improved designs and better materials which will reduce the weight of locomotives per horsepower capacity. Condensing locomotives may be produced with high thermal efficiencies. Such a locomotive would probably use a uniflow engine or turbine in place of the present type.

The use of the electric locomotive will probably increase particularly in thickly populated areas.

The Diesel-electric locomotive will apparently have its place mainly for switching service, and in localities where the passenger load is light.

The compression ratios of automobiles has increased from 4.55 in 1927 to 6.15 in 1936, and the average brake horsepower from 65.8 to 109.2 during the same period. However, the economy in miles per gallon did not keep pace with the increase in power, due to the greater speeds at which cars are operating. The average speed in miles per hour of 1936 passenger cars is 55 as compared with 36 in 1925. Automobile engines of the future are bound to be smaller, lighter, and more efficient in fuel consumption, and passenger cars will have features introduced which will make them quieter, more flexible, more comfortable, and easier to handle. It is unlikely that in the near future automobiles will be equipped with Diesel engines.

The use of Diesel engines will increase in trucks, busses, and tractors, as well as for marine purposes. It is unlikely that the Diesel motor will be used extensively, in the near future, as the prime mover for airplanes. The availability of high-octane gasolines and the replacement of carburetors with fuel injection systems will postpone any commercial application of Diesel engines to heavier-than-air machines.

Steam-driven ships will be operating at higher pressures and temperatures, and will make greater use of the devices and methods, now employed on land, to bring about better power-plant economy.

Maximum Steam Utilization.—Much progress may be expected in the near future in the field of district steam heating in connection with electric power generation. At the turn of the century there was considerable competition between electric public utilities and other electric generating stations which also sold steam for heating. This competitive situation, which may have been responsible in the past for lack of interest on the part of electric public utilities in district steam heating, has been changed, as evidenced by the growth of central heating in several of the larger cities of this country. The social significance of central heating and central power generation becomes apparent when one watches, in any of our larger cities, the hundreds or even thousands of stacks emitting clouds of smoke to foul the atmosphere. In most of our cities, even in the very largest, central plants could be located to generate steam economically and with a minimum amount of atmospheric pollution, and still be within 2 or 3 miles distance from remote steam users.

Most of the earlier district heating systems were financially impractical, because they were designed for low-pressure steam; these installations involved the use of large and expensive piping, high heat losses, and high investment costs per unit of steam delivered to

customers. By using high pressures and high velocities central steam heating costs may be greatly reduced.

Too many even of the present central heating plants operate at poor load factors. An extension of air conditioning may change this by providing a summer load of considerable magnitude. An economical central heating system may be feasible if it is a part of an electric central station; in this case highly superheated steam at pressures of 2,000 pounds or more per square inch may be passed through steam turbines and exhausted at a pressure of about 200 pounds into the heating system. More extensive central heating will remove much of the present smoke nuisance but its application is dependent upon the heating load factor mentioned before, upon research which will make available metals suitable for steam temperatures of 1,200° Fahrenheit and higher, upon new and inexpensive heat insulation, and upon greater emphasis on the part of power producers upon the use of heat and less upon central station economy. Progress in central steam heating has been handicapped in the past by transmission difficulties, which like electric transmission involves many factors difficult to control.

Maximum heat utilization will also be accelerated by cooperation of industries and utilities in the interchange of heat and power, and by utilities selling steam and hot water as well as electricity.

Research to Reduce Power Costs.—New knowledge is needed to construct steam generators which are efficient and safe at much higher temperatures and pressures than those now in use and which will at the same time be inexpensive, have high rates of output, low maintenance, a high degree of availability and adaptability to different fuels and waters. Steam generators burning fuel under pressure merit greater study.

Remote control of steam generating equipment merits greater development and application.

There is need for more research in metallurgy in order to develop metals suitable for much higher pressures and temperatures than are now used in fuel burning plants. New and inexpensive alloys are needed which will be suitable for steam temperatures of 1,200° F. and even higher, but which will not add greatly to the first cost of power equipment or to operating expenses, and which will be safe and reliable.

There is a demand for new and inexpensive metals for steam turbine blades which will not corrode in the presence of very wet steam.

More knowledge is required to insure that water entering steam generators will not injure the metals with which it comes in contact, limit the maximum operating temperature, or result in detrimental scaling, embrittlement, or corrosion.

Research in the field of welding should result in lower costs of power-plant equipment.

We now possess reasonably satisfactory means for the suppression of smoke and for the elimination of the solid particles from the stack gases of large plants. The cost of doing this, however, is great with the present separators and precipitators. Improved methods for the precipitation and for the utilization of flue dust are needed.

Better and less expensive means are needed for the elimination of sulphur from the effluent gases, salvaging if possible the sulphur.

With the greater steam temperatures in use there is need for research to develop a noninflammable lubricating oil. Present knowledge of surface phenomena will result in better lubricants.

In the not too distant future one may expect successful processing and treating of coal, so that each of its constituent elements will serve the most useful economic purpose. It seems wasteful to burn coal as a raw fuel. The smoke producing ingredients of coal, if they could be removed, would have a marketable value while at the same time a smokeless fuel would result. Fifteen percent of the coal mined in this country is carbonized.[16] There is need for basic carbonization research as between 1920 and 1930 about 50 million dollars was lost to the public by unsuccessful low temperature carbonization processes.[16] At present, there is also a lack of uses for the products of carbonization. Some are of the opinion that economic demands of the future will compel the combination of gas production, steam generation, and electric generation in coal-burning plants. Some even predict gas fired steam generators as a result of coal processing.

As petroleum fuels become more scarce, hydrogenation of solid fuel and of coal tar into petroleum derivatives will be more generally used. At present gasoline by hydrogenation costs about 2.5 times more than that manufactured from petroleum.[16]

Improved knowledge of powdered fuel technique may result in the utilization of coal in the powdered fuel form for gas manufacture in gas producers. Producer gas may thus be revived as a fuel for industrial uses.

Water power will be used more and more in combination with steam stations for peak load service, but more research is needed to develop cheaper types of dams for hydro plants.

There is need for an inexpensive switch gear. The use of the vacuum tube to replace the circuit breaker has been suggested. To an increasing extent vacuum

[16] H. H. Lowry. Proceeding 14th Fuel Engineers meeting, sponsored by Appalachian Coals Inc., May 11, 1936.

tubes may be expected to be used not only for regulation and control, but also in place of certain present types of electrical rotating equipment.

Electrostatic generators and motors may become a reality.

There is much room for research in electric power transmission and distribution. Direct current transmission of electricity may become a reality in the near future. At a recent meeting of the National Academy of Sciences an engineer for a large electrical manufacturer has reported progress in the study of the application of thyratrons to the problem of changing direct current into alternating current and vice versa. Alternating current generation and direct current transmission of electricity at high voltages, and the substitution of vacuum tubes for present switching devices may tend to reduce cost of power. New knowledge is needed about electronic tube transverters and mercury arc rectifiers in connection with electric transmission.

The benefits of electric interconnection have been discussed. It is doubtful, however, as to whether this should be extended greatly, as interconnection has as its major objective, emergency transfer of energy from the fringe of one power system to the fringe of another power system. However, a reduction in transmission losses may change the situation with reference to interconnection.

Research will prove helpful in improving present materials and in developing new methods of insulating electrically and thermally.

In marine practice new fuels should be developed to take the place of petroleum. A mixture of coal and oil in colloidal form merits research.

The above list of problems to be solved, though incomplete, indicates that cheaper power may become a reality if greater attention is given to research. Much of the progress, made since 1919, in improving fuel economy of steam power plants and in cheapening the cost of light and power may be traced to experimentation carried on by electric power utilities and by manufacturers of electrical equipment. More fact-finding research will substitute the certainty for the uncertainty and is definitely the fountain of youth for the power industry, which depends so greatly upon applied science. The exploration, through research, of cheaper methods for producing power and of better ways of using power should be encouraged. Research will reveal new possibilities and will aid in forecasting future trends. It is the door to tomorrow, a safe platform for the power industry of today, if progress is a major objective.

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II. TRANSMISSION AND DISTRIBUTION OF ELECTRIC ENERGY[17]

General

Social Implications of Electric Transmission and Distribution.—"Social changes of today are connected with inventions of the past, and inventions of today will, no doubt, foreshadow the social changes of the future."[18]

The social implications of inventions in the field of electric transmission and distribution are more difficult to crystallize than those of inventions in many other fields. First, because these inventions are of a highly specialized, technical nature that cannot and really need not be understood by the layman; second, because the social unit does not come into direct contact with them. The telephone instrument, the radio set, the washing machine, the automobile, and similar invented devices are used by the public directly. But inventions in the field of electric transmission and distribution can only be brought home to the public indirectly in the form of more dependable service, lower rates or the possibility of making electric service available where otherwise it could not or would not exist. Furthermore, transmission and distribution being of necessity of a monopolistic nature, they perforce come into contact with public interest.

Electromagnetic energy is, at the same time, the most elusive and most universal of all forms of energy. This form of energy, except for the lodestone, some electric fish, earth magnetism, and lightning in the clouds, is nowhere to be found in nature in a form which is ready either for use or abuse. It must be created from other forms of energy, at the present time either from the mechanical energy in falling or running water or from the mechanical pressure produced by steam or by exploding gases. Furthermore, electric energy, in the form in which it is used in our daily life, exists only while it is being consumed. Its "status nascendi" is simultaneous with its "status moriendi." The very elusiveness of electric energy is one of the main causes of its universality which

[17] By M. M. Samuels, electrical engineer, Federal Power Commission. Any opinions expressed herein are the author's own and are not to be taken as official expressions of the Federal Power Commission.

[18] William F. Ogburn, chapter on The Influences of Inventions on Sociology, in Recent Social Trends.

makes long transmission and wide distribution possible and desirable.

Electric transmission and distribution owes its development to systematic scientific research at least as much as it does to invention. Scientific development must therefore be included in the discussion of invention in this specific field.

Electric energy can be generated anywhere and be made instantaneously available anywhere else by means of transmission and distribution. This, no doubt, is the most important social implication of transmission and distribution.

What Is Electric Transmission and What Is Distribution?—As has been brought out in the previous chapter the two main sources of electric energy are fuel and water power, neither of which is always available at or near a center of electric consumption. Furthermore it has been shown that up to certain limitations it is more economical and more convenient to generate energy in a few large power-houses than it would be to generate it in a great many smaller power-houses. Thus power-house locations and sizes are determined by reasons of economy and convenience. Without attempting to present concise definitions, it may be said that transmission lines generally carry electric energy in bulk from points of generation to the centers of distribution, while distribution lines carry the energy from these distribution centers to the individual places of consumption. Interconnection between power-houses or power systems are generally included under transmission.

Specific Resistances to the Introduction of New Ideas.—Mr. B. J. Stern presents a general discussion of this subject in his chapter. But there are specific resistances in this particular field that may be worth mentioning. Inventions in electric transmission and distribution do not depend so much on acceptance by the public as they do on acceptance by engineers. But even among engineers there are those who like new things and new ideas because they are new and others who dislike them because they are new, and the latter form the majority, because bitter experience has taught them that those who are the first to introduce a new idea must bear the burden of a period of troubles that can only be eliminated after many improvements based on difficult operating experience. Furthermore, the manufacturing is concentrated in a few giant undertakings that may be expected to prefer selling what they have already developed at great expense rather than embark on new undertakings.

One specific difficulty is inherent in the fact that electric systems are interconnected. Any new development must be suitable to fit into existing systems as regards frequency, voltage, and other features. And any new device that may be added anywhere must be so that it will cause no disturbances anywhere else on the same interconnected system.

It would take considerable space to set forth the amount of planning, scheming, failures, disappointments, and even ridicule that those engineers have to go through who are the first to introduce new ideas in transmission and distribution. But there are always the pioneers who are ready to bear this burden, and to the credit of the American design engineers and manufacturers, it must be recognized that hardly a new important transmission line, substation or distribution system was built in the United States, even under the pressure of a World War, in which some new idea was not introduced.

The Present American Transmission System

Components of a Transmission System.—Every transmission system has three principal components. The step-up substation, generally located at a power-house, changes the electric energy from a voltage at which it is generated, say 13,200 volts to one suitable for transmitting the energy a given distance, say 284,000 volts. The transmission line proper generally consists of poles or towers from which wires are suspended by means of insulators. The step-down substation, located at a place where the energy is received in bulk, changes it from the high voltage at which it arrives there to a lower voltage, suitable for the requirement at the particular receiving point. Recently, high voltage transmission has been accomplished by means of underground cables over reasonably short distances. In each case this happened when it was necessary to carry the high voltage conductors through congested population centers.

Extent of Present Transmission System.—Polyphase alternating current transmission was inaugurated in the United States at the World's Fair in 1893 and the first large scale installation was accomplished at Niagara Falls in 1895.

Publication No. D 2 of the Edison Electric Institute reports that in the year 1933 there was, in the United States, a total of 208,097 circuit miles of transmission lines, broken down as follows:

220,000	1,948
132,000	7,918
110,000	15,820
66,000	28,623
60,000	8,994
44,000	14,553
33,000	40,357
All others over 22,000	24,258
22,000	18,314
Total 22,000 volts or more	160,785
13,200	28,449
Over 11,000, but less than 22,000	7,206
11,000	11,657

Impressions of the Transmission Map.—The Federal Power Commission recently issued the first map (not readily adaptable to publication here) of the United States on which all the more important transmission lines of the country are indicated by red lines. The map is drawn to a large scale, and yet in some parts of the East, Northeast, the South, and on the Pacific Coast the lines are so close together that one gets the impression of mere patches of red. This map does not show all the lines listed above. It only shows a total of 135,000 miles, representing the more important lines, ranging from some of the first 22,000 volt lines still in operation to the new 284,000-volt Boulder Dam lines. Practically each of these lines has its own specific design features and its own specific operating problems and a little engineering and financial history all its own. The map also shows all the more important steam and water power generating plants. The crowding of the power systems in and near the larger cities is so great that it was physically impossible even to indicate these systems on the main map, making it necessary to show a separate individual map for each of these important power centers. Heavy lines represent the highest voltages, such as 284,000 and 220,000 volts. Thinner lines represent lower voltages. The first impression gained is one of a closely woven network covering the country from Maine and the Great Lakes to Florida and Texas and from the Atlantic Ocean to Kansas. Then comes a great barren stretch from north to south and again closely woven networks in the Northwest and on the Pacific Coast. A more careful inspection discloses a number of self-contained systems, each representing a group of adjoining utilities controlled by the same interests with connections here and there between the groups. The southern systems are permanently connected to Chicago, which, in turn, is permanently connected to Boston. If this map had been presented to the great inventors and scientists in the early days of electric power, they would have proclaimed it a spider web constructed in an insane asylum. They were quite unanimous in their opinion that long-distance transmission was impossible. And yet they were the most competent men of their time, pioneers, inventors, visionaries, and dreamers of the future of power, who, without being conscious of it, established the very principles and laid the very foundation upon which our present system is built. Thus it would be folly to attempt now a prediction of what the power picture of the country will be 50 years hence. But it is necessary to plan for the immediate future. Whether we like it or not, our present conceptions and our present activities will be the foundation for that future power picture. It is, therefore, essential to subject this present spider web of transmission lines to close analysis.

The first pertinent observation is that this network of transmission lines has been developed with an utter disregard of State lines. Look at the map as long as we may, we cannot detect any relationship to State boundaries. This fact was given due cognition by the Congress of the United States when it vested jurisdiction over interstate power in the Federal Power Commission.

Next we observe that while some lines run a natural and logical course, there seems to be an insufficient reason for the existence of others. A particularly strong impression is gained that many lower voltage lines in close proximity of trunk lines of very high voltage are unnecessary and illogical. Possibly these lines were logical when they were built and became of less importance when it became necessary to provide more powerful lines, and possibly there were other reasons. Furthermore, the connections between adjoining power systems seem to be inadequate in many cases. This is particularly true as regards interconnections between city power systems and adjoining transmission network, which is of great importance from the viewpoint of national defense. New York City, for instance, is practically isolated as far as power is concerned. It depends almost entirely on generation by steam in a very few giant power-houses, all located in Manhattan, Brooklyn, and the Bronx. There are no Edison Co. power-houses in the populated Borough of Queens nor in the rich county of Westchester. Only one transmission line enters New York City, in the Bronx, from Albany, and this line is not much more powerful than to take the place of one of the few 160,000 kilowatt generators in the local power-houses. In case of war or a similar emergency, it would not be too difficult to destroy the water intakes of two or three of the large steam plants, and the city would be without power for months. And yet both in Queens and Westchester there are very favorable sites for steam plants. Furthermore, within easy reach across the Hudson the map shows a powerful 220,000-volt transmission system, which is connected with other powerful systems, and yet no connection whatever exists for supplying electric energy to New York City from this system in case of emergency. A blockade or harbor strike may also tie up the power system because the supply of coal would stop.

The conditions in many other important population and industrial centers are not dissimilar. It is evident that even if nothing but national defense is considered, a thorough study is called for to establish how far additional coordination between adjoining power systems could provide for national emergencies. First, it must be emphasized that if the intake of a steam plant or the dam of a water-power plant is blown up, it will take many months to put the powerhouse back in

service, whereas a broken transmission line can be placed in emergency operation on reasonably short notice. Second, is the fact that a new interconnecting line cannot be built overnight. It must be planned, it must be designed, rights-of-way must be acquired, transformers, switchgear and other equipment must be ordered and these take many months to manufacture. The unfortunate occurrence at Hell Gate, the absence of power at Pittsburgh and Hartford for several days during the flood of 1936 are only indications of much worse conditions that may become realities during national emergencies unless proper provisions are made in advance to take care of such situations. On the other hand, a powerhouse can be better protected against air attacks than an overhead transmission line, and underground transmission may be considered reasonably secure against such attacks. This, too, calls for careful study.

Another interesting observation that can be made when looking at the transmission system of the United States is the lack of coordination with other utility services for the combined utilization of the same rights-of-way. While there are many cases of joint pole uses by telephone, telegraph, and electric distribution systems, there are few cases of utilization of railroad or pipe line rights-of-way for long distance electric transmission lines. Quite recently, however, railroad rights-of-way in the East have been used for high-voltage transmission, either by the railroads themselves or by electric utilities. It may be assumed that as railroad electrification progresses, more use will be made of railroad rights-of-way for high-voltage transmission.

Impressions from Table 17.—The accompanying table 17 presents for the first time the plant factors utilization factors, energy losses and other important characteristics for 140 large American utility systems. The figures representing ratings of generators and outputs are from the Electrical World of May 9, 1936, but all factors and other percentages have been especially computed for this chapter.

The ratings of generators given in the table do not necessarily represent the real capacities of the respective establishments. Such real capacity can only be determined in each case after a careful study.[19] But since investment is generally related to rating and not to real capacity the ratings are sufficient for this rough qualitative analysis.

In 1935 the New York City utilities purchased 16.5 percent of their energy requirements from outside sources, Detroit 0.3 percent, Boston 18.3 percent, Milwaukee 9.3 percent, Kansas City 0.4 percent, Portland, Oreg. 5.3 percent, Tacoma, Wash., less than one-tenth of 1 percent, Seattle 3.3 percent. Of the two utilities operating in and near Pittsburgh one purchased 1.2 percent and the other 1.9 percent. This is a sufficient indication to what extent large city utilities have come to depend on their own local resources.

In the case of war, a shortage of power in large industrial centers on whom the Army and Navy depend for the supply of ammunition would be nothing short of a calamity.

Sufficient information is not available for establishing to what extent each of the transmission lines of the all-American network has been utilized. But a rough impression can be gained from a "plant factor" and "utilization factor" analysis.

> The plant factor is the ratio of the average load on the plant for the period of time considered to the aggregate rating of all generating equipment installed in the plant.[20]

When a power-house has an annual plant factor of 22 percent, it means that on the average throughout the year it operated at 22 percent capacity, or that it operated at full capacity 22 percent of the time, or of every dollar invested only 22 cents were working and 78 cents were dead investment. The plant was 22 percent alive and 78 percent dead. A low plant factor means expensive generation and generally expensive transmission and distribution, resulting in high rates to consumers of all classes. This does not imply that under present or past operating conditions higher plant factors could be had in all cases, but it certainly should be possible to improve them in most cases, thus reducing costs and rates. No doubt the low plant factors also indicate that a considerable portion of the equipment reported is no more used or useful.

We observe in the table that in some cases the plant factors are as high as 70 percent and in others as low as 10 percent and even lower in exceptional cases. It is not recorded whether or not the equipment, which is only used to a small extent, is in the rate base at its full value in each case, making it necessary for consumers to pay a return on the dead investment. It is not possible to judge in each individual case from the mere observation of the plant factor that more kilowatt-hours could have or should have been gotten out of the existing equipment, or that too much equipment was provided or that some of the equipment is old and useless and should not be in the rate base. Neither is it possible to say definitely that a very high plant factor is always an indication of inadequate reserve capacity. No doubt all these possibilities exist in some cases. But the most important observation is that the diversity of plant factors from near zero to over 70 percent

[19] For a competent discussion of this problem the reader is referred to the interim report of the national power survey of the Federal Power Commission (Power Series No. 1).

[20] Glossary of Important Power and Rate Terms, published by the Federal Power Commission, 1936.

TABLE 17.—*Data on 140 electric utility systems in the United States with output in excess of 100,000,000 kilowatt-hours—1935*

Line no.	Name of company or system	Rating of generators Dec. 31, 1935		Generated and purchased output—1935		Peak on generators (30 minute) megawatts [3]	System peak (30 minute) megawatts [3]	Plant factor percent [4]	Utilization factor percent [5]	Losses and unaccounted for, percent of total output
		Total megawatts fuel and hydro [1]	Percent hydro [2]	Total output kilomegawatt-hours (general and purchased)	Purchased percent of total output					
1	Niagara Hudson Power Corporation	1,679	61.8	7,063	17.2	1,020	1,155	39.8	68.8	13.4
2	Consolidated Edison Co. of New York, affiliates	2,348	.....	5,493	16.5	1,231	1,307	22.3	55.7	14.8
3	Pacific Gas and Electric Co	1,247	70.3	4,463	23.2	.....	858	31.4	68.8	24.5
4	Commonwealth Edison Co	875	.....	4,191	49.6	577	953	27.5	108.9	12.7
5	American Gas and Electric Co., interconnected system	966	10.7	3,819	5.1	733	733	42.8	75.9	10.8
6	Philadelphia Electric Co., system	1,125	22.6	3,210	.....	746	745	32.9	66.2	11.3
7	Southern California Edison Co., Ltd	904	54.1	3,139	.7	560	562	39.4	62.2	19.4
8	The Detroit Edison Co	811	1.2	2,535	.3	554	557	35.6	68.7	11.1
9	Public Service Electric and Gas Co. (New Jersey)	684	.....	2,269	10.8	510	527	33.8	77.0	15.0
10	New England Power Association and subsidiaries	750	45.1	2,189	22.5	422	499	25.8	66.5	13.3
11	The West Penn Electric Co. and subsidiaries	506	11.1	2,068	1.9	370	375	45.8	74.1	12.2
12	Union Electric Light & Power Co. (Missouri) and subsidiaries	721	36.6	2,010	.....	.....	390	31.8	54.1	14.5
13	Alabama Power Co	563	70.9	1,943	9.7	406	408	35.6	72.5	13.8
14	Duke Power Co	760	66.3	1,792	19.2	354	440	21.7	57.9	15.4
15	Public Service Co. of Northern Illinois	343	.3	1,697	45.3	234	191	30.9	56.6	10.0
16	Pennsylvania Power and Light Co	357	12.6	1,523	13.6	.....	305	42.1	85.4	12.2
17	The Cleveland Electric Illuminating Co	478	.....	1,458	.....	334	334	34.8	69.9	12.7
18	Georgia Power Co	383	75.7	1,446	26.0	287	326	31.9	85.1	20.6
19	Pennsylvania Water and Power Co. and Safe Harbor Water Power Corporation	311	93.6	1,430	.7	329	329	52.1	105.8	5.0
20	Duquesne Light Co	444	.....	1,403	1.2	295	295	35.6	66.4	10.5
21	Super-Power Co. of Illinois	215	.....	1,346	.....	225	225	71.5	104.7	.....
22	Montana Power Co	295	99.7	1,292	2.3	.....	203	48.9	68.8	13.3
23	Columbia Gas and Electric Corporation and subsidiaries	382	.....	1,252	.....	.....	309	37.6	80.9	11.3
24	Consumers Power Co	403	36.6	1,234	8.4	258	282	32.0	70.0	16.8
25	The Edison Electric Illuminating Co. of Boston	368	.....	1,225	18.3	251	322	31.0	87.5	13.7
26	The Milwaukee Electric Railway and Light Co. and affiliated companies	519	3.8	1,210	9.3	.....	263	24.1	50.7	14.7
27	Chicago District Electric Generating Corporation	200	.....	1,169	.....	197	197	66.7	98.5	.....
28	Consolidated Gas Electric Light and Power Co. of Baltimore	231	.....	1,114	80.4	103	244	10.8	105.6	8.4
29	Northern States Power Co	468	38.1	1,098	6.7	.....	241	25.0	52.1	19.7
30	Carolina Power and Light Co	248	82.7	1,060	34.0	.....	237	32.2	95.6	16.7
31	Puget Sound Power and Light Co	320	67.4	915	.7	203	205	32.4	64.1	25.5
32	Ohio Edison Co	313	.6	877	3.6	175	180	30.8	57.5	11.2
33	Washington Water Power Co	145	99.9	854	44.6	.....	171	37.3	117.9	17.7
34	City of Los Angeles, bureau of power and light	111	100.0	798	66.7	108	183	27.4	164.9	12.9
35	Associated Gas and Electric system (eastern Pennsylvania and New Jersey group)	241	9.1	795	19.8	153	170	30.2	70.5	13.2
36	The Tennessee Electric Power Co	242	55.0	783	22.4	86	153	28.7	63.2	23.8
37	Potomac Electric Power Co	220	.....	725	21.1	.....	169	29.7	76.8	15.5
38	Kansas City Power and Light Co	247	.....	653	.4	130	132	30.0	53.4	10.6
39	Public Service Co. of Indiana	125	3.4	643	13.5	109	132	50.8	105.6	15.2
40	The Connecticut Light and Power Co	166	34.9	632	35.1	.....	137	28.2	82.5	10.1
41	Portland General Electric Co	169	55.4	583	5.3	128	130	37.3	76.9	17.9
42	Louisiana Power and Light Co	87	.....	572	17.4	.....	105	62.1	120.7	6.7
43	Utah Power and Light Co	223	17.4	564	35.8	.....	115	18.5	51.6	17.6
44	Virginia Electric and Power Co	157	18.5	531	21.7	.....	111	30.2	70.7	13.8
45	Houston Lighting and Power Co	185	.....	518	4.9	.....	100	30.4	54.1	12.3
46	California Oregon Power Co	115	87.0	515	1.8	99	99	50.2	86.1	16.0
47	Hetch Hetchy water supply, power division (San Francisco)	83	100.0	508	.....	84	84	69.9	101.2	6.2
48	Oklahoma Gas and Electric Co	183	.....	508	6.1	98	98	29.7	53.6	15.9
49	New York State Electric and Gas Corporation group (Associated Gas and Electric System)	71	19.7	505	47.3	56	89	42.8	125.4	12.6
50	The Toledo Edison Co	165	3.0	493	37.5	87	98	21.3	59.4	12.5
51	Northern Indiana Public Service Co	115	16.2	464	11.8	.....	88	40.6	76.5	15.1
52	Constituent utility companies of Western Massachusetts Companies	152	59.2	460	27.7	.....	86	25.0	56.6	15.6
53	Central Maine Power Co	122	88.9	460	5.0	88	90	40.9	73.8	14.8
54	The Ohio Public Service Co	130	.....	453	16.1	87	105	33.4	80.8	11.4
55	Texas Power and Light Co	100	1.0	449	3.7	.....	89	49.4	89.0	21.2
56	Los Angeles Gas and Electric Corporation	149	.....	437	1.9	118	103	32.9	69.1	12.1
57	Idaho Power Co	82	99.6	435	6.6	.....	70	56.5	85.4	16.8

[1] 1 megawatt = 1,000 kw.

[2] 1 kilomegawatt-hour = 1 million kwh.

[3] Company practice varies as to the period for which the peak is determined. Data were requested on a 30 minute basis, but some reported other periods. For details see Electrical World of May 9, 1936.

[4] Plant factor $= \frac{\text{total generated (mwh)} \times 100}{\text{total rating of generators (mw)} \times 8760}$; mw = megawatt; mwh = megawatt-hour = 1000 kwh.

[5] Utilization factor $= \frac{\text{system peak (mw)} \times 100}{\text{rating of generators (mw)}}$

NOTE.—Systems are arranged in order of total output (generated and purchased).

SOURCE.—Tables I and II of supplement to Electrical World, May 9, 1936.

TABLE 17.—*Data on 140 electric utility systems in the United States with output in excess of 100,000,000 kilowatt-hours—1935*—Continued

Line no.	Name of company or system	Rating of generators Dec. 31, 1935		Generated and purchased output—1935		Peak on generators (30 minute) megawatts	System peak (30 minute) megawatts	Plant factor percent	Utilization factor percent	Losses and unaccounted for, percent of total output
		Total megawatts fuel and hydro	Percent hydro	Total output kilowatt-hours (generated and purchased)	Purchased percent of total output					
58	Montana Electric Co.	73		424	5.0	76	99	63.0	135.6	
59	Louisville Gas and Electric Co.	192	41.7	423	18.0	81	81	20.6	42.2	10.0
60	Associated Gas and Electric System (South Carolina group)	227	68.1	419	2.3	128	128	20.6	56.4	7.5
61	Minnesota Power and Light Co.	125	76.0	408	.2		90	37.2	72.0	15.9
62	Associated Gas and Electric System (Western Pennsylvania group)	140	34.3	400	1.7	83	83	32.1	59.3	17.2
63	Tennessee Valley Authority	244	75.4	387		180	180	18.1	73.8	
64	Rochester Gas and Electric Corporation (Associated Gas and Electric System)	133	36.7	385	38.3	55	80	20.4	60.2	14.7
65	Central Illinois Public Service Co.	81		369	50.1	52	87	26.0	107.4	17.3
66	Chelan Electric Co.	59	100.0	365			56	70.6	94.9	
67	Indianapolis Power and Light Co.	167		360	15.2	81	82	20.9	49.1	10.7
68	Texas Electric Service Co.	101		358	1.6		75	39.8	74.3	20.5
69	Nevada-California Electric Corporation System	69	88.4	356	25.0	59	66	44.2	95.7	26.4
70	Nebraska Power Co.	98		355			74	41.3	75.5	8.2
71	Public Service Co. of Colorado	126	29.4	354	1.3	78	79	31.7	62.7	16.8
72	Northwestern Electric Co.	52	18.4	352	64.6		80	27.4	153.8	13.5
73	City of Seattle—department of lighting	128	76.6	350	3.3	80	88	30.2	68.8	20.8
74	Arkansas Power and Light Co.	99	66.0	347	44.6		55	22.2	55.6	19.5
75	Hartford Electric Light Co.	127	.8	341		86	89	31.2	70.1	10.0
76	New Orleans Public Service, Inc.	108		340			79	35.9	73.1	10.8
77	Kentucky Utilities Co.	74	33.0	323	16.4	55	62	41.7	83.8	13.2
78	The Columbus Railway, Power and Light Co.	133		316	.3	70	70	27.0	52.6	8.0
79	The United Illuminating Co.	155		308		79		22.7		13.1
80	Central Illinois Light Co.	89		291	1.7	60	63	36.7	70.8	9.5
81	Wisconsin Power and Light Co.	87	42.5	287	10.6	60	64	33.7	73.6	17.7
82	Long Island Lighting Co. system	169		284		84	84	19.2	49.7	20.5
83	The Scranton Electric Co.	120		276	.5	60	60	26.2	50.0	12.3
84	City of Tacoma, department of public utilities	148	77.0	276		67	55	21.3	37.2	16.2
85	Kansas Gas and Electric Co.	70		266			52	43.3	74.3	14.9
86	Salt River Valley Water Users' Association	70	100.0	261	11.1	62	62	37.8	88.6	15.1
87	Gulf States Utilities Co.	76		258	35.1	43	49	25.2	64.5	15.2
88	Wisconsin Public Service Corporation	88	51.1	258	4.7		52	32.0	59.1	16.9
89	Penn Central Light and Power Co. (Associated Gas and Electric System)	81	6.2	254	.4	55	55	35.6	67.9	13.7
90	Florida Power and Light Co.	139		249	1.5		74	20.2	53.2	22.9
91	Virginia Public Service Co. (Associated Gas and Electric System)	88	18.2	247	7.4	55	56	29.6	63.6	17.6
92	Pacific Power and Light Co.	29	72.4	243	40.6		60	56.8	206.9	23.0
93	Jersey Central Power and Light Co.	142	.2	242		68	59	25.6	41.5	17.6
94	Dallas Power and Light Co.	83		241	2.5		54	32.3	65.1	14.4
95	The Empire District Electric Co.	86	22.9	240	1.4	50		31.5		18.7
96	Louisiana Steam Generating Corporation	45		234		36		59.5		
97	Birmingham Electric Co.	12		231	100.0		46		383.3	13.6
98	West Texas Utilities Co.	53		230	1.9		49	48.5	92.5	18.1
99	Atlantic City Electric Co.	120		224	.1	50	50	21.2	41.7	16.2
100	Southwestern Gas and Electric Co.	43		220	17.9	33	42	48.0	97.7	14.7
101	Public Service Co. of New Hampshire	84	48.3	219	10.0	45	53	26.8	63.1	12.5
102	Public Service Co. of Oklahoma	79		219	14.1	40	45	27.2	57.0	14.4
103	Central Hudson Gas and Electric Corporation	36	66.7	216	60.4	41	46	27.1	127.8	15.8
104	Blackstone Valley Gas and Electric Co.	35	5.0	213	96.1		54	2.7	154.3	8.7
105	Central Power and Light Co.	75	20.0	210	16.3	28	40	26.7	53.3	25.7
106	Des Moines Electric Light Co.	74	.7	206		45		31.8		16.9
107	San Diego Consolidated Gas and Electric Co.	74		205	1.3	53	53	31.3	71.6	15.2
108	City of Detroit, public lighting commission	80		204	9.1	49	55	26.4	68.8	7.0
109	Memphis Power and Light Co.	54		197			47	41.7	87.0	14.0
110	New Bedford Gas and Edison Light Co. (Associated Gas and Electric system)	92		196		48	48	24.3	52.2	9.1
111	Inland Power and Light Co.	47	100.0	192			51	46.6	108.5	
112	Iowa Public Service Co. and Sioux City Gas and Electric Co.	75	2.7	180	4.6	41	44	26.1	58.7	16.8
113	San Antonio Public Service Co.	100	.7	179	27.3	29	38	14.9	38.0	16.8
114	Pennsylvania Power Co.			178	100.0		40			7.5
115	Northern Indiana Power Co.	23	1.6	177	99.1	12	41	.8	178.3	22.2
116	Cumberland County Power and Light Co.	77	41.7	170	17.6	39	53	20.7	68.8	14.8
117	City of Cleveland, department of public utilities	50		169		39		38.5		13.2
118	Mississippi Power and Light Co.	19		165	94.2		38	5.2	200.0	20.0
119	Tampa Electric Co.	35		155	6.3	37	37	47.2	105.7	13.3
120	Turlock and Modesto Irrigation Districts	35	97.1	154	.3	39	39	50.1	111.4	8.7
121	Connecticut Power Co.	10	100.0	148	75.5	11	39	41.4	390.0	4.3
122	Indiana Service Corporation	31		147	69.2	20	38	16.7	122.6	9.1
123	Interstate Power Co. (Delaware) and Subsidiaries	70	9.4	147	22.8	31	42	18.5	60.0	20.3
124	Iowa Electric Light and Power Co.	78	2.3	144	.5	33	33	21.0	42.3	12.0

TABLE 17.—*Data on 140 electric utility systems in the United States with output in excess of 100,000,000 kilowatt-hours—1935*—Continued

Line no.	Name of company or system	Rating of generators Dec. 31, 1935		Generated and purchased output—1935		Peak on generators (30 minute) megawatts	System peak (30 minute) megawatts	Plant factor percent	Utilization factor percent	Losses and unaccounted for, percent of total output
		Total megawatts fuel and hydro	Percent hydro	Total output kilowatt-hours (general and purchased)	Purchased percent of total output					
125	Delaware Power and Light Co	23		143	100.0		29		126.1	7.3
126	Luzerne County Gas and Electric Corporation	55		131		43	25	44.5	45.5	9.2
127	South Carolina Power Co	36	44.7	128	2.6	28	28	39.7	77.8	14.5
128	Iowa-Nebraska Light and Power Co. and Maryville Electric Light and Power Co	43	5.1	125	30.9	21	30	23.0	69.8	13.9
129	Kansas City, Kans., Board of Public Utilities	39		124		26	26	36.2	66.7	10.0
130	Florida Power Corporation (Associated Gas and Electric system)	58	24.3	123	8.5		29	22.1	50.0	16.8
131	Bangor Hydro-Electric Co	31	100.0	120		26	26	44.2	83.9	15.9
132	Mississippi Power Co	19		118	82.9	5	26	12.1	136.8	19.6
133	Staten Island Edison Corporation (Associated Gas and Electric system)	48		116	3.0	30	30	26.7	62.5	13.1
134	Western United Gas and Electric Co	41	.3	114	18.3	29	25	26.0	61.0	15.8
135	Tennessee Public Service Co	6	2.4	114	99.6		24	.9	400.0	12.7
136	City of Lansing, Board of Water and Electric Light Commissioners	67	1.5	108		30	30	18.3	44.8	6.5
137	Southern Indiana Gas and Electric Co	40		105	1.7	28	28	29.5	70.0	12.7
138	El Paso Electric Co	57		104	.2	24	24	20.8	42.1	13.2
139	City of Jacksonville municipal electric light plant	55		104		26	26	21.5	47.3	13.9
140	Central Illinois Electric and Gas Co	45	2.7	104	80.7		24	5.1	53.3	12.4
	Total	30,546	29.0	102,964				32.4		

is a definite indication for the need of a fundamental study to find out if rational coordination will not make it possible to make some use out of the dead investment. Such a study should also assist in the elimination of the dead limbs from the power system organism. A mere glance at the great diversity in plant factors gives the impression that it should not be too difficult to bring about both greater economy and more reliable service by better coordination.[21]

There is no doubt that the low plant factors and low utilization factors with the resulting enormous amount of dead investment is brought about by the fact that our power system, including generation, transmission, and distribution must be planned to take care of the peak, which only lasts a short period of time on any power system. While greater diversity brought about by coordination improved the situation considerably and further coordination may be expected to improve it some more, the question of how to take care of peak conditions should receive more attention than it has in the past. Many methods have been suggested and tried out, principally in European countries, but the problem is still with us. Repumping is being used in many places in Europe and in one or two places in the United States. The excess generating capacity during off-peak hours, either water power or steam power, is being used to pump water back into the reservoirs of water-power stations and the water, so accumulated during off peak, is being used during peak time to drive generators. Heat storage is another method that is being used in some cases. Heat is being accumulated in the form of hot water during the off-peak period and this heat is used during peak hours for driving generators. But these methods still call for generators, transmission lines, transformers, and distribution systems to be of sufficient capacity to take care of the peak. The saving is principally in operating expenses, fixed charges generally becoming higher due to the need of installing the pumps or heat-storage equipment. Generally, there are certain definite loads at definite locations that bring about the high peaks. If it were possible to provide some means of direct power supply at these locations to function automatically so that they operate only during the peak and are out of service the rest of the time, it would not be necessary to have the generators in the large power-houses, the transmission lines and even some of the distribution systems of sufficient capacity to take care of the peak. In some places in Europe, storage batteries have been resorted to for this purpose. What is really needed is the invention of a prime mover and generator designed specifically to operate only a short period of time each day. The present Diesel does not seem suitable for this purpose. It must be of the same size and hence the same cost whether it is called upon to operate 1 hour a day or 24 hours a day. It is known that some American inventors are now at work on the development of engines, small in size, low in cost, suitable for operating automatically for short periods of time and not requiring attendance. If and when such a reliable engine appears on the market, it should

[21] See System Plan Alternatives Analyzed for Executives, by M. M. Samuels, Electrical World, Oct. 31, 1931.

be possible to introduce enormous savings in power-system planning and at the same time introduce numerous sources of power for emergency purposes.

The utilization factor is the ratio of the maximum demand of a system or part of a system to the rated capacity of the system, or part of the system, under consideration.[2]

The first cost of a power-house or a power system, and thus the fixed charges, are not determined by the number of kilowatt-hours that the power-house produces or the system sells, but by the number of kilowatts taken out of the power-house or the system at peak time. Since the fixed charges represent the greater portion of the cost of power, the utilization factor becomes a very important feature in the determination of rates. Table 17 indicates that on many systems the utilization factors are very low. Here, too, it is not intended to imply that under present or past operating conditions the utilization factors could have been higher in all cases. But there is no doubt that a detailed study will reveal many cases in which there is actual excess capacity that could be utilized to help out other systems and other cases in which the excess is junk which should be removed to permit a healthy growth of the system.

Another interesting observation that table 17 permits is the great diversity of energy losses among the various systems. In some cases as much as 25 percent of the energy generated is lost in the transmission and distribution conductors, transformers, etc. This represents a serious waste of natural resources, which national planning should be able to reduce.

Low plant and utilization factors and the resulting high fixed charges are brought about to a great extent by peak and reserve features, which represent very intricate problems on any interconnected power systems. But a simple illustration will serve as a fundamental exposition of the main features involved. Assume a residential community in which a small power-house is located to provide electric energy only to the residents of this community. Such a power-house would have to be of sufficient capacity to take care of the peak load, which would probably be in the evening. The power-house would have two or three generating units of suitable sizes. At least one such unit would have to be kept in reserve, because any of the other units may be disabled at times. A power-house in an adjoining similar community would likewise have to have at least one unit for reserve purposes. But if the two power-houses are connected together by means of a transmission line, one reserve unit would serve the purpose of both power-houses, because the probability of a unit being disabled in each of the two power-houses at the same time is very remote. Thus we have the simplest case of two small power systems, each supplying load of the same character, both having their peaks at the same time, and yet a transmission line between the two may make it possible to get along with a considerably smaller investment. The feature of diversity has not yet entered the picture, the saving brought about by the transmission line is one of spare capacity of "required reserve" only.

When a manufacturing establishment is located close by which needs electric energy only in the daytime, when residential consumers need very little or no energy, the two existing small power-houses may be able to supply sufficient electric energy to this industrial establishment without installing any additional generating capacity. This additional saving by a transmission line is brought about by what is known as "improved diversity."

As more and more power-houses are connected together by transmission lines, the total required generating capacity per unit of production becomes less due both to the proportionally smaller required reserve and improved diversity. The power requirements for cotton ginning in Texas and Mississippi slow down at a time of the year when the requirements for irrigation power grow in Louisiana. Similar diversities in industrial requirements prevail in various parts of the country. The more diversified the industries are that take power from the same interconnected transmission system the more economical becomes the utilization of the facilities of the power system, and the lower should be the rate charged to the consumers.

Natural Resources and National Defense.—The people of the United States are becoming educated to the importance of conserving their natural resources. From a national viewpoint, it is no less than a crime to generate electric energy in inefficient power-houses where perhaps 2 or 3 pounds of coal must be consumed for generating 1 kilowatt-hour of electric energy when the same kilowatt-hour can be produced in a modern steam plant with less than 1 pound of coal. This is not a mere matter of economy. From the national viewpoint it is decidedly desirable to preserve every pound of coal for the future. On an interconnected system it should be possible to so schedule the operation of the various power-houses that the system consumes a minimum of fuel.

Furthermore, every pound of coal, gallon of oil, or cubic foot of natural gas that is burned up is gone forever, whereas water power is continually recreated by nature. An interconnected transmission system should make it possible to develop all feasible water-power sites and generate as much electric energy as possible from water power, preserving every possible pound of fuel for future generations.

[2] Glossary of Important Power and Rate Terms, published by the Federal Power Commission, 1936.

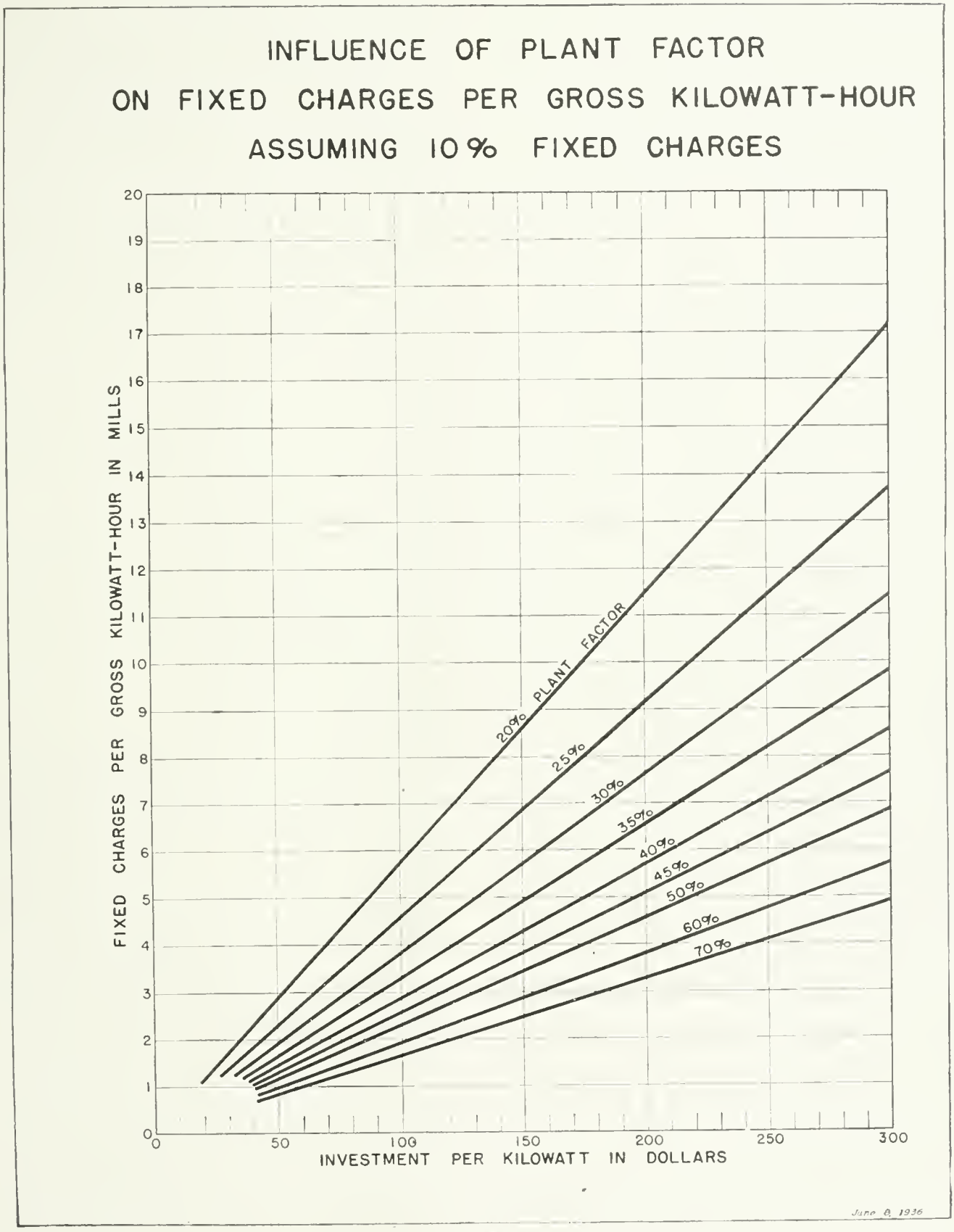

INFLUENCE OF PLANT FACTOR
ON FIXED CHARGES PER GROSS KILOWATT-HOUR
ASSUMING 10% FIXED CHARGES
FIXED CHARGES PER GROSS KILOWATT-HOUR IN MILLS
INVESTMENT PER KILOWATT IN DOLLARS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
0
50
100
150
200
250
300
20% PLANT FACTOR
25%
30%
35%
40%
45%
50%
60%
70%
June 8, 1936

FIGURE 43.

Power has become as important an arm of national defense as the police and fire department, the Army and the Navy. This defense is important not only in wartime, but also in peacetime. In his foreword to the interim report of the national power survey (Power Series No. 1) Vice Chairman Basil Manly of the Federal Power Commission remarked:

> Control of power is a social as well as an engineering and economic problem. If the flow of electricity should suddenly cease, it would be a national catastrophe of unimaginable magnitude. Our homes, streets, and highways would be in darkness. Streetcars, subways, elevators, and conveyors would suddenly stop and even railroad transportation would be impossible at night without electric signals. Radios would cease to function and the ships on the high seas would be immediately endangered. Factories would be forced to shut down, modern bakeries would cease to produce bread, the water supply of cities would be interrupted by the failure of the electric pumps and perishable food would rapidly deteriorate for lack of refrigeration. There would be no fire alarm, no burglar alarm, no telegram, no telephone, and few newspapers. Electric light and power has come to be almost as essential an element in our daily lives as the bread we eat and the water we drink. Modern civilization would collapse with the failure of the sources of electric light and power.
>
> The national safety and welfare, the productivity of our industries and the comfort and conveniences of our homes are thus dependent upon the maintenance at all times of an abundance of electricity available at rates which will permit its use wherever it is needed. We must, therefore, not only provide for our immediate requirements but we must also plan for continued improvement and expansion of the Nation's electrical systems to meet the demand that may be reasonably anticipated for the future.

At the time metropolitan papers were inclined to take these remarks lightly. But it was not long before the same papers found themselves forced to report an actual occurrence in almost the same language as that used by Mr. Manly. Only one of the many power-houses serving New York City went out of service accidently and yet one and a half counties were without electric light, elevator service, radio, etc. Surgeons performed operations by the light of pocket flashlights. Passengers were suspended in elevators between floors for a long time. The city subway was not only without power, but also without light, and candles sold at a premium.

This was followed by the flood in the early part of 1936 during which many cities that depend principally on local power generation were without light or power for days. On December 28, 1936, the entire city of Newark, N. J., was in darkness for several hours due to a failure in a single power house.

A certain degree of coordination does exist in some parts that were affected by the flood, and there the benefits of such coordination were clearly demonstrated.

After reciting the partial log of actual operation of a power system at Pittsburgh during the recent flood, the statement is made:[23]

> * * * All the power distributed by Duquesne Light Co. was obtained through interconnections. Even this borrowed power could be obtained from the Pennsylvania Power Co. and the West Penn Power Co. only because they, in turn, had been able to borrow extensively.
>
> The West Penn Power Co.'s 160,000-kilowatt plant at Springdale as well as the plant at Ridgeway were flooded out. The Connellsville plant had been entirely shut down for awhile, but by the time Springdale was put out of commission, Connellsville was again operating at something less than half capacity. The capacity of the Lake Lynn station was cut nearly 30 percent because of the high tailrace. In addition to the city of Pittsburgh, West Penn was also supplying the city of Cumberland, Md.
>
> In the meantime, ordinary communication facilities were crippled by one of the worst sleet storms ever known in the district. Based on no more than a vague rumor that the West Penn Power Co. was having difficulties, the Niagara, Lockport, and Ontario Power Co. and the Pennsylvania Electric Co. began pumping power into the West Penn system, this despite the fact that the latter company was having flood troubles of its own. The Monongahela-West Penn system from West Virginia supplied upwards of 15,000 kilowatts to the West Penn system from the south. At Windsor, an additional 50,000 kilowatts was supplied to West Penn by the Ohio Power Co., despite the fact that their own Toronto River power station was badly flooded. The Ohio Power Co. was able to do this only by reason of the fact that they are tied to the Appalachian and other southern systems, to Cleveland, and through the Indiana Public Service Co. to Chicago.

New Ideas in Transmission

Lightning.—Lightning has been the greatest enemy of long-distance transmission, since a lightning stroke any place on a system may cause damage at any other place or put the whole transmission system out of commission. The study of lightning has been the most difficult and most costly of all transmission-line studies.

Lightning is the discharge of an electric charge between a cloud and the earth. It has been known for ages that lightning prefers to discharge from clouds to anything that has a good connection to permanently moist earth, such as trees, pipes, etc. A cloud will frequently produce an opposite charge on the transmission-line conductors that run parallel to it, and after this opposite charge becomes of sufficient magnitude, a discharge from the cloud to the conductors will take place with damaging results, because the line conductors are not connected to ground. The discharge, in the attempt to reach ground, will jump across insulators, through transformers or even through generators. Close to important equipment so-called lightning arresters are generally installed

[23] The Electric Journal, May 1936.

to provide a prescribed path to ground for the lightning discharge, thus avoiding damage. On top of high-voltage transmission lines, so-called ground wires are frequently carried the full length of the line. These wires carry no usable current, and serve only the purpose of taking lightning charges and discharges, thus preventing the lightning from discharging into the current-carrying conductors. Frequently, a line transverses a stretch of rocky or dry soil, making it difficult to find a good ground connection. In such cases, so-called counterpoise systems have recently been used with good results. A counterpoise is a wire in the ground or close to the ground the full length of the line and connected to the ground wherever a good connection can be made, and connected also to all the towers. The actual functioning of the counterpoise is quite involved in mathematics, and is really more than that of a mere ground wire. Suffice to say that it has offered excellent additional protection against lightning wherever it has been used. On one line in New England the installation of a counterpoise reduced lightning trouble by over 90 percent.

Large Equipment.—The transformer is the keystone of a transmission system, because the transformer makes it possible to change any voltage to any other voltage, and to do this with an efficiency approaching 100 percent. There seems to be no physical limitation to voltages for which transformers can be built.

Each of seven single-phase transformers for Boulder Dam is 55,000 kilovolt-amperes, 284,000 volts, the highest voltage ever used anywhere except in the laboratory, where 10,000,000 volts are now available. Each of these transformers with its oil weighs 387,000 pounds net, is over 20 feet long, over 13 feet wide, and nearly 32 feet high. Such transformers are now so designed that the probability of damage by lightning is reduced to a minimum.

Next in importance in the development of high-voltage transmission lines is probably the oil-circuit breaker. When a short circuit occurs anywhere on a transmission system and the affected section of line is not separated from the system very quickly, the whole system may become affected, switches may open automatically anywhere and leave whole communities without electric service; transformer and generating equipment may be damaged or the whole system may lose its rhythm and fall out of step, and it may take hours to again secure a harmonious operation of all the power-houses on the system. But, in addition to the urgency of clearing a short circuit as quickly as possible, it is necessary to design the circuit breaker for breaking the enormous short-circuit currents that may develop on an important interconnected system.

One of the most recent developments is the type of circuit breaker used at one end of the Boulder Dam line. It has a rupturing capacity of 2½ million kilovolt-amperes, a shipping weight of 450,000 pounds (including 28,000 gallons of oil), is able to clear a short circuit in one-twentieth of a second, and costs well over $100,000.

To indicate that new ideas are continually coming to the front, it is well to mention that for the other end of the same transmission line oil circuit breakers are being used for the same voltage, the same rupturing capacity, the same speed of operation, but with a shipping weight of only 130,000 pounds, made possible by a new and ingenious principle in breaking heavy arcs. It is significant to note, however, that the two breakers, radically different in design, type, and quantity of material, cost substantially the same.

Thus, we see that switching problems, important as they may be, and enormous beyond conception, are being solved in each case for the rendering of safe and reliable service from power systems representing unprecedented concentrations and combinations.

Developments by Small Manufacturers.—During the depression, progress has gone forward in the development of what is generally known as the small manufacturers' high-tension equipment. Such small manufacturers have neither the financial means nor the research institutions nor the manufacturing facilities for developing and building the enormous power transformers, circuit breakers, large lightning arresters, and similar expensive equipment. But there are many cases in which it is necessary to serve small communities or large industries from high-voltage lines, and where the cost of large switching and protective equipment becomes prohibitive. Instead of oil circuit breakers, it is necessary to get along with fuses, air switches, and small arresters, which may not offer the same degree of protection as the heavy equipment, but must be as adequate as they can be made for the available money. In this field the smaller manufacturers in close cooperation with operating men did practically all the pioneer work. To their credit, it must be recognized that handicapped as they were by limited credits and an utter lack of orders during the depression, they courageously continued the development work that they had been carrying on for years and are now offering better switches, better fuses, better small lightning arresters, and better connecting devices.

The small manufacturers are greatly handicapped by not having at their disposal any facilities for testing high-voltage equipment, such facilities being away beyond the financial means of the small manufacturer. Those who are responsible for maintaining service on high-voltage lines naturally desire to have all parts subjected to severe tests before they use them, but the small manufacturers have not the means to build

expensive testing institutions, and therefore are working under a considerable handicap.

Conductors and Insulators.—For very high voltage, alternating-current transmission, it is desirable to have the transmission-line conductors hollow. Space does not permit to present an elaborate explanation for the need of hollow conductors. Suffice it to mention that for many years this feature respresented a considerable problem and to report that the difficulties have quite recently been overcome. One type of such hollow conductor is now in operation on the 132,000-volt transmission line of the Pennsylvania Railroad and another on the 284,000-volt Boulder Dam line.

Insulators for overhead lines have been one of the principal sources of trouble because they form practically the only part of the transmission system that cannot be made of unbreakable metal. They are generally made of porcelain, even though recently considerable progress has been made in the development of glass insulators. The most recent development in this field is a 70,000-volt pin-type glass insulator, made of one solid piece of glass. Both porcelain and glass are brittle and subject to breakage through mechanical and electro-magnetic causes. Lightning or excessive voltages from other causes may produce high temperatures or other forms of stress of sufficient strength to break insulators. The importance of this feature will be realized when it is remembered that one broken insulator may put a whole line or a section of a line out of commission. Millions of dollars have been expended on insulator research and the repair of insulator damage. It may also be said that after many years of trouble reasonably satisfactory methods are now available for attaching the metal parts to the insulators. The shape of the insulators for different operating conditions has likewise undergone considerable development, but in general the various insulators offer about the same appearance as they did many years ago. Most of them are of the petticoat type. Furthermore, it may be possible to improve the insulation considerably by using insulators of different sizes in the same string or by using more insulation on one part of a line than on another. Plastic materials are still too expensive, but there seems to be no doubt that eventually plastic insulation will take the place of porcelain and glass, thus adding greatly to the reliability of transmission lines.

New Cable for High-Voltage Underground Transmission.—As mentioned above, there is very little underground high-voltage transmission. The progress made in the development of high-voltage cable is, therefore, indeed remarkable. Paper is now practically the only insulating material used on high-voltage cable. In the early days a failure was a common occurrence. But the study of the insulating mediums by manufacturers, operating men, and scientists resulted in cables that hardly ever fail. It was found that the principal cause of cable failures was the formation of voids in the insulating material through drying or shrinking. Small electric discharges took place in these miniature voids, which eventually resulted in the destruction of insulation and a failure of the cable. New oil or inert gas is being introduced into the cable and is being kept there at all times under pressure. This not only makes voids impossible, but paper kept permanently soaked in oil is also a better insulator. This particular study, known as the "study of dielectries" in a systematic manner and on a large scale, though of comparatively recent origin, has resulted in great improvements not only in cable insulation but also in transformer insulation, condenser insulation, and other fields. Progress is going ahead and greater improvements may be expected in the near future after the chemist, who is only now entering this field of research, has had his chance. The highest voltage used so far on underground cable in the United States is 132,000 volts, but in France there is an installation operating at 220,000 volts.

Direct-Current Transmission

Direct-current transmission has recently received much attention, possibly more among laymen than among engineers. Considerable development has been going on quite recently in the laboratories of the various manufacturers. But the manufacturers hesitate to commit themselves definitely in writing on all possibilities of direct-current transmission, an attitude which cannot be considered unreasonable. In the early stages of any development, a manufacturer cannot commit himself to any limit, because when a little later an actual case comes up he may, and generally is, able to go beyond that limit.

The author's impression, after discussing the subject with all manufacturers involved, is that if and when an actual case arises in which the need for direct-current transmission can be shown, all the manufacturers in the field would be able to furnish adequate equipment.

The opinion is frequently expressed that the question of direct-current transmission is a mere matter of economy. Recent experience with high-voltage underground alternating-current transmission seems to indicate the advisability of not establishing economy as the only possible limiting feature in the introduction of new ideas in electric transmission. No one claims that the present 132,000-volt underground installations are more economical than would have been overhead construction. It was mentioned above that all existing high-voltage underground installations were brought about by force of circumstances and not

by economy. Even admitting that at present no definite cases are at hand where direct-current transmission would be an absolute necessity, it would be unwise to state definitely that no such necessity will arise in the future.

All manufacturers seem to agree that the ground will not be used as a return for the circuit, that a full metallic return will be provided, and that the most likely arrangement for direct current will be three-wire with grounded neutral. Electrolysis and other insurmountable troubles from stray currents are therefore not to be expected.

Furthermore, manufacturers and scientists agree that for very long distance underground transmission or even for shorter high-voltage underground installations, direct current seems logical from a cable viewpoint. There may even arise cases in which underground direct-current transmission would cost less than overhead alternating current transmission. This, if proved to be true, would be a great incentive to direct-current transmission. However, it is not possible to establish under what circumstances such cost reduction could be brought about because it is impossible to secure a definite price on equipment until a definite case is at hand.

None of those who are engaged in the study of the subject from a manufacturing or other commercial viewpoint are thinking in terms of high-voltage direct-current generation. The present direct-current high-voltage generators in the laboratory, so spectacular and interesting that they received considerable newspaper notice, are for bombarding of atoms, but not suitable for power purposes. This, however, does not preclude the possibility that even now some inventor has a conception of a practical direct-current high-voltage generator. Neither is direct-current distribution being considered as a general proposition. The prevailing opinion is that the transformer will remain for a long time the best means for voltage transformation, even when direct-current transmission is used. The present activity of changing over the old direct-current distribution systems into alternating current is expected to continue until direct-current distribution is practically eliminated. But there may be cases in crowded streets, in which a number of radial primary direct-current feeders would prove economical or even become a necessity.

Thus the present conception of direct current in a possible large power system is one of transmission only, generation and distribution remaining alternating current.

"*Rectifiers*" have been known for some time. They are stationary devices without moving parts for changing alternating current into direct current. Such rectifiers of the mercury-vapor type were first used to operate certain types of arc lamps, and are still used in some cities for this purpose. The vacuum tube as a rectifier is known to every radio amateur. There are also some small metallic rectifiers that are used for charging batteries and as convenient small sources of direct current for auxiliary use on power systems. Mercury-vapor rectifiers of considerable sizes have been used to provide direct current for reasonably heavy-duty railway services, such as the Philadelphia subways, the city-owned subways in New York, the suburban service of the Delaware, Lackawanna & Western Railroad, and other cases. But the use of the inverter is of very recent origin The inverter changes direct current to alternating current without the use of rotating machines.

A 33,000-volt direct-current line for connecting a 5,250-kilowatt, 40-cycle alternating-current generating station to a 60-cycle system, 17 miles away is now in experimental operation. It must be emphasized that this is not a connection between two systems but of a single powerhouse to a system.

The sizes quoted here are quite small as compared with the sizes that would be needed for large power purposes.

The advantages claimed variously for direct-current transmission may be summarized here:

1. The possibility of tying two systems of different frequencies without the need of rotating frequency changers.

2. The same conductor can carry more direct-current amperes than alternating-current amperes. Some experts claim that the same insulated cable could carry five times as many direct-current amperes as alternating-current amperes.

3. The same amount of insulation is good for a much higher voltage under direct current than under alternating current.

4. So-called stability problems are practically nonexistent when direct current is used.

5. Corona losses from both overhead and underground conductors are much smaller for direct current than for alternating current. The skin effect does not exist under direct current. Dielectric losses in cable insulation are very low. Ionization in voids in the insulation is not likely to cause trouble. Hence hollow conductors are probably unnecessary on overhead lines and oil or gas unnecessary in underground cable, if direct current is used.

6. Dr. W. M. White, manager and chief engineer, hydraulic department, Allis-Chalmers Manufacturing Co., writes under date of July 31, 1936:

> Power transmission by direct instead of alternating current fundamentally benefits its hydroelectric generating plants in that the requirements of exacting speed or cycle control is eliminated. This not only simplifies the governing

equipment of the turbines but permits also of a substantial range of revolutions or cycles when such variation results in improvement of efficiency otherwise sacrificed when the available seasonal head varies to a marked extent and which variation becomes particularly felt with medium and especially with low head developments.

This may make it economical to develop many water-power sites that are now considered uneconomical.

In conclusion, it must be emphasized that the most important unknown factor is the cost of equipment.

The Future Transmission System

Coordination.—No doubt the most important near-future development will be greater coordination of existing facilities. There seems to be no immediate need for very long transmission lines as such, but coordination studies indicate that there are many places in which new tie lines would make possible a better utilization of existing equipment. The larger the systems that are to be connected, the less saving may be expected from a reduction of the required peak capacity, even though there are individual cases in which this saving may be considerable. The greatest saving may be expected from a reduction of the required reserve capacity. The expected benefits from better coordination may be summarized briefly as follows:[24]

1. Reduction of fixed charges and resulting reduction in rates by improvement in plant factors and utilization factors and a reduction of energy losses.
2. Better provision for emergencies, such as floods, strikes, wars, or other sudden disturbances.
3. A more elaborate network of transmission, making power available at low rates where it is not now available at all or can only be made available at high cost.
4. A better utilization of the water-power resources of the country and saving of fuel.
5. Decentralization of industry. While it is known that in many industries the cost of power represents only a small portion of the cost of the product, there are industries that cannot be located at the most desirable places because power is not available at all or its cost is prohibitive. Coordination is expected to make power available at such places at reasonable rates, making it possible in turn to provide better and cleaner living conditions for industrial workers, farmers, or those who in the future are expected to be part farmers and part industrial workers.
6. Better utilization for electric transmission of the facilities owned by other utilities, such as railroad rights-of-way, pipe-line rights-of-way, etc.
7. Coordination by utilities with power-houses owned by industrial establishments for better utilization of the power facilities by both.
8. Transmission over greater distances at night or other off-peak, low-load periods for better utilization of water power that would otherwise go to waste.
9. A more rational handling of the peak problem, with the possible provision of generator units at peak-load locations, making it unnecessary to design the whole system for peak load.

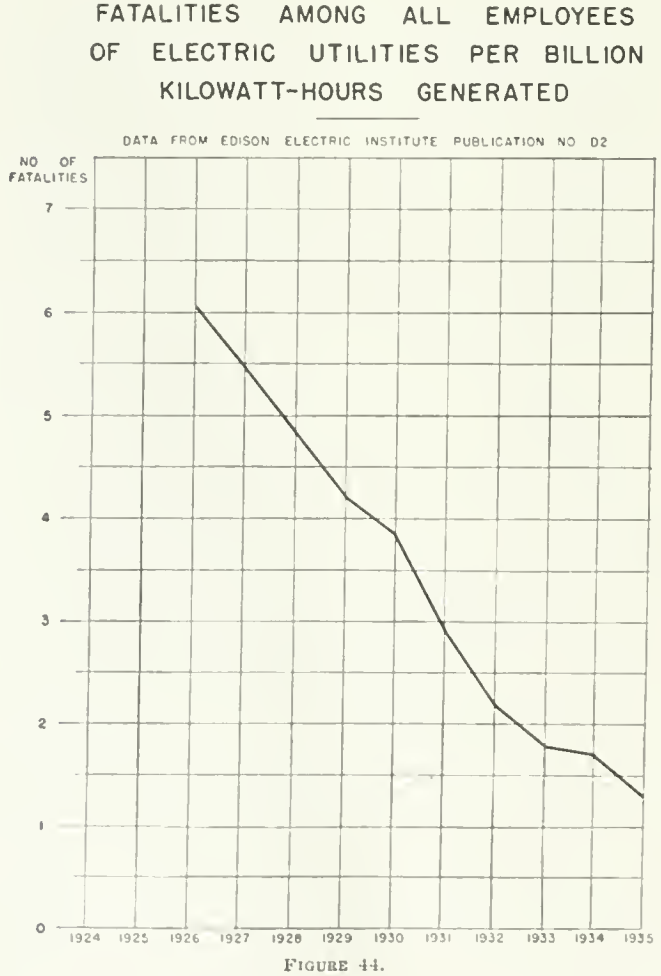


FIGURE 44.

New Insulation for Overhead Lines.—In the present transmission line, porcelain or glass insulators are mounted on poles or steel towers. In the future, the insulators may be of unbreakable plastic material and even the whole supporting structure may be built of plastic insulating material.[25]

Underground Transmission.—Aviation and national defense will force many transmission lines underground. When airplanes become as numerous as automobiles, overhead lines will become almost impossible. Underground lines offer a better protection against attack from the air than do overhead lines. Direct-current transmission and further development in cables will make underground construction economical.

New Substations.—The future will see the elimination of the unsightly and complicated high-voltage substation with its many high-voltage insulators, each

[24] Future System Planning and Station Design Rationalized by M. M. Samuels, Electric Light and Power, November 1934.

[25] Dreaming of Future Line and Bus Insulation, M. M. Samuels, Electrical World, Feb. 9, 1929.

of which is a source of trouble. The future station will be completely submerged in nonexplosive oil.[26]

New Switchgear.—Further activity of scientists in the field of switchgear will bring out new circuit breakers, based on new scientific principle and sold at prices that are not prohibitive.[27] [28]

New Transmission Brought About by Decentralization of Generation.—Very few giant powerhouses will be built. Few new steam plants will contain units of over 50,000 kilowatts. The powerhouses will be located at more logical places and interconnected underground. The generation will be at interconnection voltage, say 33,000 volts or 66,000 volts, thus doing away with large transformers, reducing cost, and increasing reliability.

Independent Testing Institution.—There will be a large independent high-voltage testing institution, where small manufacturers as well as customers can have high-voltage equipment tested in a competent and independent manner.

Direct Current Transmission.—There will be a considerable amount of direct-current transmission, mostly underground.

Fuel Transmission.—A considerable portion of energy will be in the form of fuel transmission by pipe lines instead of electric transmission, the power being generated by steam-electric plants at load centers.

Distribution

Introduction.—Distribution can be best explained as the retail business of the electric utility industry. Electric energy is delivered wholesale to a step-down substation or several substations within a community or on the outskirts of a community, from one or more powerhouses, over one or more transmission lines. From the substation or substations, primary distribution circuits at reasonably low voltages are carried through the streets either overhead or underground to supply energy to, domestic, commercial, industrial, and other classes of consumers. In some communities all the generation is done locally and the primary distribution lines emanate directly from powerhouses instead of substations. The voltages of these primary distribution lines, reasonably low as they are, are still too high for the small consumer's purposes. The primary distribution voltage is never less than 2,300 volts, and frequently as high as 27,000 volts. Small transformers, generally known as distribution transformers, are, therefore, provided on poles or in manholes to step the energy down to a voltage suitable for consumers, mostly 220 volts for power purposes, and 110 volts for lighting purposes.

Radial and Network Distribution Systems.—In smaller communities the radial system of distribution is generally employed. Individual primary circuits radiate from a substation or a powerhouse, each circuit furnishing energy to a certain district. Individual transformers are supplied from each primary circuit, each transformer individually furnishing energy over individual secondary wires to a group of consumers or to one larger individual consumer. The secondary wires emanating from one transformer are not connected to those emanating from another transformer, even though in some cases special provision is made for one transformer to take over the burden of another in case the latter is incapacitated.

In condensed load areas in large cities, the so-called alternating current network has recently become popular. Cables are run under all the streets, parallel to each other as well as at right angles to each other, and solidly connected together at each intersection. This constitutes the so-called secondary network.

Energy is supplied to any consumer from the nearest point of any of the cables that make up the network or grid. Primary circuits are run under the streets from substations or powerhouses. Comparatively large transformers are located at suitable points under the streets, receiving their energy from the primary circuits and in turn supplying energy into the network, at points where two or more cables cross and are interconnected.

The radial system of distribution may be compared to a set of individual brooks, each supplying water to a few consumers, independent of any other brook. The secondary network can be compared to a lake occupying the whole area under a city or a section of a city. Anyone in that area can take water out of that lake. Water is supplied to the lake from various brooks at various convenient places. In the first case, when one brook becomes dry, those depending upon it will immediately be without water, whereas in the second case, even if several brooks cease to supply water to the lake, there are many others that continue to do so, and the consumers of water may be altogether unaware of the fact that one or more brooks are dried up.

Similarly, in a radial distribution system, if a short circuit occurs on an individual circuit, those who depend on it will be at once without electric energy, whereas in the case of a network system, even if one or more supply circuits or one or more transformers become incapacitated, the other circuits and transformers continue to supply energy to the network and the consumers continue to take that energy without even knowing that anything happened.

[26] A Transformer Station of the Future, M. M. Samuels, Electrical World, Dec. 22, 1923.

[27] Hindrances to Circuit Breaker Development, M. M. Samuels, Electrical World, Feb. 5, 1927.

[28] High Tension Oil Circuit Breakers (p. 203), by Roy Wilkins and E. A. Crellin, McGraw-Hill Book Co., 1930.

The advantages of the network to the consumer are thus self-evident, but for economic reasons such networks are only used at present in congested load areas.

Lack of Planning in the Past.—Electric distribution grew as America grew. No one could have possibly predicted the rapid growth of American cities or American industries. During that rapid period of growth, any systematic planning of distribution for several years ahead became out of date on short order. Furthermore, during the rapid growth of the industry, when millions upon millions were spent on generation and transmission, practically all the attention of engineers and manufacturers was concentrated on these two fields. The engineers were so wrapped up in generation and transmission that many of them considered distribution as too lowbrow to merit their attention. Distribution was frequently left to the lineman, purchasing agent, and storekeeper, and many distribution systems grew up to give the impression of crazy quilts, without any apparent logic either in circuit sizes, voltages, or locations, and sizes of transformers. It was not possible to secure any data on the number of kilowatt-hours got out of a kilovolt-ampere of installed transformer capacity or a pound of copper. Such information on the degree of utilization of distribution equipment is still scarce.[29]

In many cases there was very little coordination in the planning of electric distribution with other utility services, such as telephone, telegraph, gas, street car, water, steam, police and fire signals, sewers, etc. Even now in many communities, three or more poles can be seen close together, each taking care of a different utility service.

In larger cities, the same lack of coordination is evident underground. Figure 45 is an illustration of the congestion of various utilities on the surface and under the street of a reasonably large city, and there are many cases that represent even more complicated mazes. It has not been uncommon for two or more utilities to open and close a street in the same location immediately after one another for the purpose of repair or extension.

Overhead Coordination.—The first serious attempt at coordination of design by various utilities was the joint use of poles for electric distribution, telephone, street cars, etc. Much congestion and unsightly construction was eliminated and is still being eliminated, and considerable economy brought about by such joint use of poles. For many years the telephone companies did not permit electric utilities to run electric circuits of over 5,000 volts on telephone poles. Very recently, after carefully studying possible hazards and various kinds of interferences, agreements have been reached by telephone companies and some electric utilities to carry higher voltages on jointly owned or jointly used poles.

Underground Coordination.—In many cities there have recently been decided indications of coordination of underground utility services. But here, in congested population centers, the difficulty of finding space under the street may become an even greater problem than the one of traffic on the surface. Cities of the future may find themselves forced to provide continuous tunnels under the main streets, in which all utility services would be arranged systematically and accessible for inspection and repair. It would then be unnecessary to break up the streets. Such tunnels could also be used for truck traffic.

Greater Coverage to Include Rural and Farm Areas.—Much is still left to be done toward rationalization of distribution planning. Considering the fact that distribution must be a monopoly in most cases if for no other reason than the physical impossibility of finding space in city streets for competing services, it is assumed to be the duty of a distribution system to render service to anyone who needs it and at fair rates. Recently, the idea has been expressed that for the same reason distribution systems should be expected to extend their services to the surrounding and adjoining rural and farm areas, spreading the cost over the whole area and making it possible for farmers to receive electric service at reasonably low rates. Coordination of electric distribution with highway lighting, possibly using the same primary circuits on the same poles, and further coordination with telephone service, may in the near future reduce the cost of rendering service to outlying districts. Mr. Cruse, in his chapter, shows that automobile accidents have been on the decrease in the daytime, but on the increase at night, indicating the great need for good highway lighting which would make it possible to drive at night without the use of headlights.

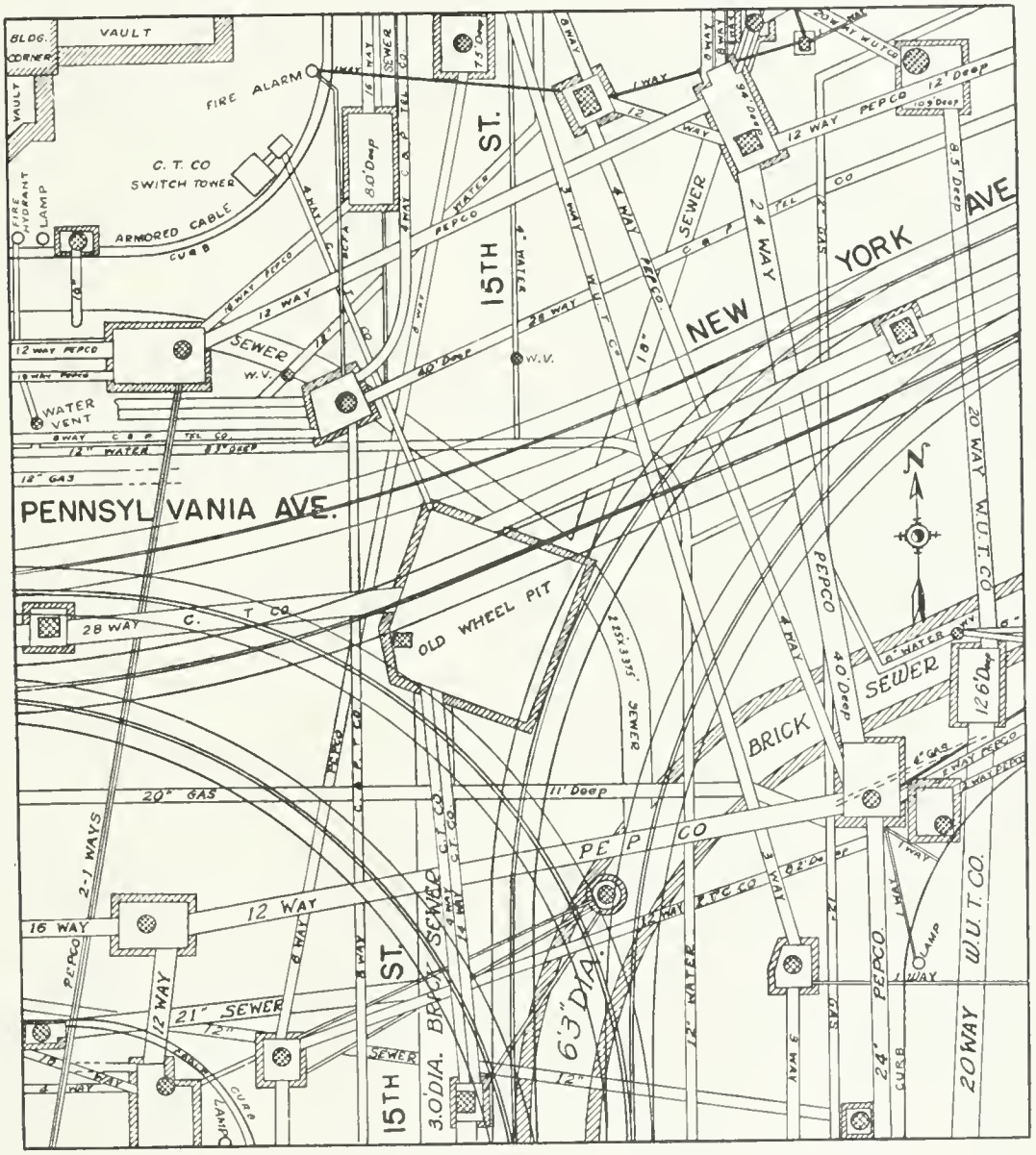
Science and Development.—In distribution, too, science and engineering development played as important a part as invention, and possibly even more so. Here, too, study and development have very recently been carried on by both engineers and manufacturers to such an extent that electric distribution quite recently emerged as an important and respected part of electrical engineering.

New Distribution Transformers.—The humble distribution transformer has received an unprecedented amount of attention as to efficiency, reliability, safety, and cost. Transformer efficiencies are so high now that they are approaching 100 percent. All manufacturers are able to furnish transformers that for

[29] See Valid Cost Comparisons in Distribution, by M. M. Samuels, Electrical World, Aug. 25, 1934.

ELECTRIC RATE SURVEY FEDERAL POWER COMMISSION

TYPICAL CONGESTION OF UTILITY SERVICES ON THE STREET SURFACE AND UNDERGROUND IN LARGE CITIES



COURTESY OF THE DEPARTMENT OF SANITARY ENGINEERING, GOVERNMENT OF THE DISTRICT OF COLUMBIA.

June 6, 1936

FIGURE 45.

many purposes can be considered lightning proof. Manufacturers and university laboratories concentrated their attention on the study of transformer oil, with the result that nonexplosive oil is now available. It is still too expensive for many purposes, but most new developments are expensive. As time goes on, explosion-proof oil will, no doubt, become sufficiently low in price to be used in every distribution transformer, unless transformers are developed that need no oil at all.

For many years engineers concentrated their efforts on the improvement of transformer efficiency rather than on the reduction of the first cost. Quite recently, principally through the efforts of the Rural Electrification Administration, there has come a realization of the importance of reducing the first cost and maintenance cost of distribution. Transformers of simpler design can now be had at a considerably lower cost. No doubt, the importance of cheap but dependable transformers will be realized even more as time goes on, and eventually there will emerge a low-cost transformer with reasonably high efficiency, sufficiently simple in design for anyone to handle safely, and sufficiently reliable in service to give practically no trouble at all. This is not a utopian prediction, but something that transformer designers and inventors are actually aiming for.

In the early stages of the alternating-current network the transformer was a source of trouble and worry. The network transformers, generally much larger than the ordinary distribution transformers, are located neither in supervised substations nor in visible locations on poles. They are located in manholes, and when they develop trouble no one knows about it. Hence there were many serious transformer explosions causing considerable damage. But the introduction of a nonexplosive oil and numerous improvements in design details based on operating experience reduced such explosions to a minimum. The problem cannot yet be considered as finally solved. But improvements are being made so steadily and rapidly that final elimination of all transformer explosions cannot be too far away.

The rationalization of transformer sizes, numbers, and locations, features that cannot be considered apart from each other, and the relationship of these three features to the voltages and sizes of primary and secondary circuits, has likewise been subjected to serious study in the last few years, and resulted in many cases in increasing the capacity of existing facilities, combined with improved service and reduced maintenance cost. The public demand for lower rates has, no doubt, served to stimulate more serious engineering attention to distribution.

New Cable and Wire.—Improved types of cable and wire for underground and overhead distribution have been emerging from the various manufacturing establishments and give promise of reducing cost and improving service at the same time. New insulating materials that can stand higher temperatures than rubber are the result of tenacious laboratory studies. One such material is a composition resembling rubber, another is spun glass, and paper insulation is continually being improved. Copper sheath instead of lead is one of the interesting developments for underground as well as for overhead suspension, and insulated conductors containing steel strands for strength promise to bring about the elimination of the troublesome, unsightly, and clumsy messenger suspension of overhead cables. But the industry is still awaiting a good cable which would be sufficiently low in cost for primary and secondary rural and farm circuits.

New Capacitors.—For both voltage regulation and power-factor correction improved capacitors are now available. Both series and multiple capacitors have been tried out with some success. As an indication of the most recent improvements in capacitor design, it need only be mentioned that the dimensions of a new 15-kilovolt-ampere capacitor are the same as those of an old 3-kilovolt-ampere unit. This was made possible by the development of better paper and nonexplosive oil. This revolutionary rapid improvement in the design of the capacitor, which has been known and used for over 100 years, is indeed remarkable. And it is important to note that this improvement was brought about by a painstaking study of materials.

Both series and parallel capacitors may be expected to become very popular both for voltage regulation and power-factor correction on radial distribution systems, making the distribution both more dependable and more economical.

Voltage Standardization.—Widespread standardization of voltages made quantity production of equipment much easier, and as standardization continues the cost of equipment may be expected to go down, resulting in lower fixed charges to the utility and lower rates to the consumer.

The Alternating-current Network System.—The development of the alternating-current network system in cities represents by far the most important feature in the progress of electric distribution in very recent years. Publication No. A–9 of the Edison Electric Institute, published in 1933, contains reports on the operation of 52 such network systems in the year 1931. These 52 systems had in that year a total installed network transformer capacity of 1,719,224 kilovolt-amperes, representing an increase of 36 times over 1925, in which year only six alternating-current networks were reported to exist. The peak loads of

network systems increased 28½ times from 1925 to 1931. Thirty-nine of the fifty-two systems representing 86 percent of the transformer capacity used 120/208 volts, 3-phase for secondary service.

The old Edison three-wire, direct-current network gave about as satisfactory and dependable service as can be expected, particularly because with the direct-current network it was possible to use stand-by storage batteries, so that even when all sources of supply failed, energy could be had from these batteries. But it was necessary to convey all the current at low voltage from the substations to the consumers, because transformers cannot be used with direct current. On one hand, this was a very expensive method of distribution, and on the other, as the load grew the streets became so congested with cables that it was difficult to find space for new cables to take care of the load.

Radial distribution from alternating-current substations also proved to be inadequate both from the viewpoint of economy and that of service reliability. The alternating-current network offers a system almost as reliable as the old three-wire direct-current systems. The batteries are missing, but there is such a multiplicity of supplies that the interruption of service to a customer is very unlikely. No matter where a short circuit may occur in the network, the service supply to customers remains intact.

Even though there are some overhead networks, the majority are underground. What made the network system so popular and dependable is the invention of the so-called network protection. It is an automatic switch installed on the low-tension side of each transformer, principally to prevent current from flowing backward from the network into the primaries. It is a device too intricate to be explained to a layman, which is even now being continually improved. Suffice it to say that without the network protector, the alternating-current network would not have been possible.

The network system is still in its early stages of development and offers a number of engineering problems that cannot yet be considered as finally solved. The matter of transformer explosions, mentioned above, is probably the most important of these problems. But operating men and manufacturers are pushing ahead toward solution, and it may be predicted that networks will continue to grow as long as there are dense population centers.

A very important advantage of the network is the elimination of the hundreds of small transformers ranging in size from 1½ kilovolt-amperes up, with their fuses, lightning arresters, and numerous other accessories, and hence the elimination of the need of inspection, repair, and maintenance at hundreds of places all over the distribution system.

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Servicing Customers from Distribution Systems.—Reports are now emerging from various parts of the country, indicating that the depression period was utilized for improving and rehabilitating that portion of the distribution system which lies between the distribution system proper and the customers' premises. Unsightly and hazardous connections which in the majority of cases were the result of a lack of planning, are being eliminated everywhere. In many cases the house entrance switches and meters are now located outside the house instead of in the cellar, so that in case of fire or flood all the electric circuits in a house can be disconnected by opening the switch outside, and the meter reader can read the meter without entering the house.

But the meter itself still needs considerable improvement. Its principal fault lies in the fact that the scales are as unintelligible to the customer as Egyptian hieroglyphics. If customers had a better understanding of the meter readings and could check their own bills, they would no doubt use more electric energy. A search through the patent files discloses at least one patent recently issued on a meter which can be set up for any rate schedule that may be in force, and sealed. It then registers the amount of the bill rather than the kilowatt-hours or the kilowatts of demand, on the order of the scales used in grocery stores. The hope may be expressed that such meters will soon be in general use.

Rationalization of Distribution as an Aid to the Greater Use of Household Appliances.—From a social viewpoint, it is desirable to introduce all possible domestic appliances into the home and on the farm. For this purpose it is desirable to introduce rates low enough to promote the greatest use of electric energy without encouraging economic waste. It should be possible, in many cases, to furnish more energy with existing facilities without adding to the fixed charges.[30] For the purpose of establishing how much energy could thus be furnished at incremental "variable charges without adding to the fixed charges," it would be necessary to secure a great amount of statistical data on the demand diversity of electrical appliances, the demand diversity of transformers, etc. In fact, it would be necessary to know to what extent a distribution system has already been used and how much more energy it could handle without adding new facilities.[31] Such a study is yet to be undertaken on a large scale.

In the case of the network, both transformers and cables are generally larger than they need be for

[30] See Glossary of Important Power and Rate Terms, published by the Federal Power Commission, 1936.

[31] Valid Cost Comparisons in Distribution, M. M. Samuels, Electrical World, Aug. 25, 1934.

carrying the load. Here a short circuit is not intended to open a switch or blow a fuse. It is intended to burn itself out. Transformers and cables are designed to carry the short circuit for a considerable time. If they had to carry more load they would not have to be larger. Generally, 300-kilovolt-ampere and 500-kilovolt-ampere transformers are used on network systems, and frequently even larger transformers, and generally they are not loaded to more than half of their capacity. Here is a good case for promotional electric rates to encourage the greater use of major electrical appliances.[32]

Future Distribution.—Here the future seems easier to predict than in the field of transmission:

1. The unsightly and hazardous overhead construction will eventually disappear and will be replaced by underground construction, mostly of the network type.

2. Meters will register the amount of the bill and rates will be so simplified that each consumer will be able to check his own bill.

3. An elaborate study of the distribution system and of the incremental cost of furnishing additional energy with existing facilities will result in rates which will promote the greatest use of electric energy in the home and on the farm without encouraging economic waste.

4. There will be greater coordination with other underground utility services, such as water supply, gas, sewers, and communication. In congested cities there will be tunnels to carry all these services, making it unnecessary to break up the streets at all for repairs and additions.

5. There will be a greater application of series and multiple capacitors for voltage regulation and power-factor correction.

6. Means will be found to eliminate transformer explosions altogether. New types of cheap, rugged, and safe distribution transformers will be developed.

7. There will be greater coverage of the distribution system to include widespread rural electrification and highway lighting which will eliminate the need for headlights.

8. In congested areas, direct current will be used on primary circuits.

9. There will be emergency sources of electric service in all important public places, such as theaters, hospitals, schools, etc., so that when the main source of supply fails there will always be sufficient lighting for essential emergency service and for exits.

[32] See Glossary of Important Power and Rate Terms, published by the Federal Power Commission, 1936.

Acknowledgment

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VI. THE CHEMICAL INDUSTRIES

By Harrison E. Howe[1]

Introduction

A definite list of industries which can be classed as chemical cannot be made with the expectation of unanimous agreement. The oldest classification is that of the Bureau of the Census, which in the biennial census of manufacturers, 1933, listed 4,672 establishments with products valued at $2,060,433,682. The items there included are as follows; Ammunition and related products; baking powder, yeast, and other leavening compounds; blacking, stains, and dressings; bluing; bone black, carbon black, and lampblack; candles; chemicals not elsewhere classified; cleaning and polishing preparations; compressed and liquefied gases; druggists' preparations; drug grinding; explosives; fertilizers; fireworks; glue and gelatin; grease and tallow; ink, printing; ink, writing; mucilage, paste, and other adhesives; paints and varnishes; patent or proprietary medicines and compounds; perfumes, cosmetics, and other toilet preparations; rayon and allied products; salt; soap; tanning materials, natural dyestuffs, mordants and assistants, and sizes; and wood distillation and charcoal manufacture.

To this list the Bureau of Foreign and Domestic Commerce would add: Alcohol, ethyl, and distilled liquors; linseed oil, cake, and meal; oils, essential; turpentine and rosin; and matches.

There are other important industries which quite properly could be added to such a list, such as the cellulose industries, rubber, and petroleum. Strictly speaking, where the process involves a change in composition, chemistry is involved and the step becomes a chemical process.

Chemistry and Its Relation to Other Sciences

A clearer understanding of the scope of this discussion may be had if we begin with a definition of chemistry for the purpose of the report. Textbooks and dictionaries provide a variety of such definitions, but chemistry may be regarded as one of the fundamental or basic sciences which has to do with the composition of matter and with certain of its characteristics under a variety of physical conditions such as pressure, temperature, and degree of concentration. Mathematics and physics are also fundamental sciences. The three are so closely associated, not only in scientific research but in the application of results to industry and to everyday life, as certainly to make physics and chemistry well-night indistinguishable in much of the work of the scientist. Mathematics in addition to being a science in its own right is one of man's most useful tools.

The other sciences rely to a considerable degree upon the theories and data of chemistry and use them freely in the pursuit of many specialties. This has given rise to a number of hyphenates in science, such as biochemistry, physiological chemistry, and physical chemistry. These names describe areas originally borderlands but now almost separate sciences, and in these much of our most important recent advance has been made. The thought in the inscription on the Baker Chemical Laboratory at Cornell University, which says "To the science of chemistry in the quest of truth, to the art of chemistry for the welfare of man, to the training of youth in a science ministrant of sciences this building, the gift of George Fisher Baker, is dedicated", is fully justified.

The influence of the science chemistry upon world trends becomes far greater when considered in its relation to a number of problems in biology, medicine, and even the social sciences than might otherwise be the case. It is not unlikely that in future a better understanding of biochemical processes with resulting control of some of them may very distinctly alter the characteristics of human beings and bring about changes within a short period of time which otherwise might occur, if at all, only over a period that is not likely to be measured.

Chemistry and Industry

The products of the chemical industry are rarely recognized by the ultimate consumer as such, because they do not reach him as individual products. They constitute one of the best examples of how the finished products of one industry may be the semifinished or even raw materials for some other industry. In a certain sense that is a weakness, because any industry needs a sympathetic understanding on the part of the public and particularly the official public. One may see a modern structure in the course of erection and be very conscious of the importance of the steel industry. He may go anywhere in these United States and have reason to marvel at progress in automotive engineering. These and many other industrial products are self-evident and are easily identified with a special industry. But those who see such evidences cannot be expected to have any appreciation of the chemical control which lies back of the production of satisfactory steel, nor of the unnumbered contributions

[1] Editor, Industrial and Engineering Chemistry.

from the various special fields of chemistry to the perfection of the modern motorcar.

The public has not been particularly interested in the contributions, let us say, to the electric lamp of today. It merely knows that the lamps are more efficient, they cost less, and they give better light than those of a few years ago. The average man is quite amazed and frequently intrigued by the account of the contribution of a single scientist, Irving Langmuir, whose work in the field of pure science developed the fact that burning in an atmosphere of an inert gas such as argon or nitrogen, an incandescent-lamp filament gave a better light with a lower consumption of energy than was possible in such a vacuum as was attainable commercially in these lamp bulbs. Of course, when he is told that but for such work the country would pay a million dollars a day more for its light bill, he is impressed; but before he grasps the value of the contribution we must resort to such statistics or perhaps explain that to obtain the same amount of light for a hundred hours by the use of candles as is possible with a modern 100-watt lamp would cost on the order of 200 times as much as the electricity.

Just as the science, chemistry, is one ministrant to sciences, so the chemical industry is one which serves all other industries. Fully to grasp the truth of this statement one needs only remember that few of the raw materials provided naturally are ready for use and that in most cases a chemical change takes place before they are suitable. Even where a change in physical state is involved—as for example, sawing a tree into useful lumber—the operations are likely to be carried on with tools which would be inefficient and unsatisfactory except for the contributions of chemistry. Thus the chemistry of metals, otherwise known as metallurgy, is involved in the manufacture of a suitable circular or band saw, the chemistry of the lubrication necessary for the operating mechanism, and similar contributions.

Synthetic Resins and Plastics

Some thought should be given not only to the trends in chemistry and to those within the chemical industry, but possible effects in other industries. Not infrequently a chemical discovery so impresses industry in general as to effect far-reaching results. There has just been observed the twenty-fifth anniversary of the incorporation of the pioneer company in the field of synthetic plastics. Dr. Leo H. Baekeland recognized in an experiment discarded by an organic chemist because the product was not crystalline an opportunity to produce a new structural material. Following a considerable period of research and development, the synthetic resinoid bakelite, which is a condensation product of formaldehyde and phenol, two well-known common chemicals, was the first of what has become a long and ever-increasing line of synthetic resins, resinoids, plastics, and molding compounds. Struggling at first for a place in a market where shellac and hard rubber were well established these new materials have made their way with increasing rapidity, until today we find literally hundreds of trade-named compounds, each with special characteristics and designated for special applications.

The day of keen competition with the older materials is largely past and we have entered an era which is of the new competition of our day, where different products with special characteristics are offered for the same service. The result has been great improvement in all sorts of molded articles and the production at reasonable costs of items which otherwise would not have been made. Now these plastics and resins seeking new fields of utilization give the ultimate consumer improved service and a far greater choice.

Let us examine this a little further. The ability to produce a structural material which would come from the mold bearing distinctly all its characteristic marks and requiring no further finishing cuts, polishing, or grinding operations; with metal parts molded in place; with intricate designs a possibility, as well as a wide range of color, opened up a new field for useful and decorative articles. These resins began to appear in automobiles; throughout radio, as special insulation; decorative material, from cigar holders to umbrella handles and jewelry. The development of the mechanical details involved in molding made such objects cheap enough to be used as toys, while the resistance to corrosion of the bonding resin and such fillers as asbestos made possible new tanks and similar equipment, linings to protect metals, pipe lines and fittings, and sheets for structural purposes. The more recently perfected injection molding in which the hot resin is forced into the cool mold has speeded up the operation, has widened the field of application. Thus new industries have been created, as was new competition for wood, metal, and ceramic products.

Research has been described by a banker as an activity which only serves to make banking hazardous. He referred, of course, to what may take place in an industry that is not alive to the constant changes which science, if successful, must bring about. Elaborating his point, this banker said that he might make a loan to an industry on a perfectly satisfactory balance sheet, only to find when the loan became due that someone had devised a better product, a more efficient method, or perhaps something entirely new to render the same service; thereby putting the debtor out of business. The chemical industry founded upon research and dedicated to change is more fully aware of

this possibility than perhaps any other. The well-informed chemical manufacturer is not likely to say "it cannot be done," unless he pauses and adds "that is, not now." He can never be sure but that some new theory useful as a tool; some new material for equipment, without which a given reaction may be uneconomical; or some discovery of a way to accomplish a given end may come from the research laboratories.

Fixed Nitrogen

It may be recalled that although a laboratory experiment in the middle of the eighteenth century showed that when an electric spark occurred in a tube, some of the nitrogen in the atmosphere was oxidized, it was not until the first decade of the twentieth century that this phenomenon became the basis of the fixed nitrogen industry by the electric arc. These time lags between first observations of a natural phenomenon and the founding of a chemical industry based upon it are not infrequent, though they may seldom be so long in duration.

However, when early in the present century investigations were undertaken by Haber to find a way to cause the nitrogen of the atmosphere and hydrogen from steam to unite and cool, many of his colleagues and the savants of other countries were free to say that it could not be done. But that was before much was known about catalysis, before the days of high-pressure equipment and the utilization of high temperatures as they are known today. Haber and his associates learned the conditions under which these gases not only would combine but how to accelerate the reaction so as to make it commercially attractive. Activity in a number of research laboratories attests to the fact that we still know very little about catalysts except that they are a group of substances or compounds which by their mere presence do accelerate reactions in a predetermined direction without themselves being changed and without their being present in the final product.

One of the best understood examples is that of the hydrogenation of vegetable oils to prepare solid fats which compete with lard. This work can be accomplished by passing the oil at the right temperature countercurrent to a stream of the gas hydrogen in the presence of finely divided metallic nickel which serves as the catalyst. The conditions of the operation cause the molecules of the liquid fat or oil to take up atoms of hydrogen and upon cooling we have a solid fat. But there is no nickel in these fats, nor is the nickel substantially changed by the operation. A different catalyst, or sometimes a number of different catalysts, may be used for a particular manufacturing process. There are many such, and for the most part the synthetic products of today are the result of some type of catalytic reaction.

The fixation of atmospheric nitrogen is perhaps one of the best examples of how an accomplishment in the chemical industry may profoundly affect other industries, and indeed the balance of power in the world. Prior to fixation by one or another chemical process, the sources of nitrogen for industrial uses were the Chilean nitrate deposits and byproduct ammonia from the distinctive distillation of coal in making coke and gas.

The process for the fixation of atmospheric nitrogen by the cyanamide route had become commercial in 1906. This process involves the use of calcium carbide, was more suitable for wide use than the arc process which because of the high power requirements was confined to countries possessing natural advantages in extraordinarily cheap water power. The arc process began to be commercial in 1907, and these two, while affording some competition with Chilean nitrate, caused the latter no serious concern because of their higher costs. Other countries began the erection of cyanamide plants, and these have continued in production. With the advent of the Haber process about 1912 and particularly when the country of its origin, Germany, demonstrated its utility as a source of fixed nitrogen during the war, there began to be intensive interest in this particular process. The result has been that in nearly every other country of importance plants using some modification of the Haber process and many improvements upon it have sprung up, until today the total world production by the fixation of atmospheric nitrogen by such methods is greater than by all other methods combined. According to recent statistics prepared by the United States Tariff Commission, the total by all processes, including Chilean nitrate, as of January 1, 1934, was 5,082,300 short tons, of which synthetic processes—that is, the Haber process and its modifications—accounted for 3,241,800 tons. Byproduct processes yielded 621,500 tons; the cyanamide, 539,000; and from Chile came 690,000 short tons.

Now the result of this chemical development has created an entirely new industry. It has complicated enormously the financial problems of Chile. It has had a bearing on the fleets that used to be maintained to carry nitrate from Chile to various parts of the world. It has made necessary training men with skill to operate the new processes and has created a world surplus of fixed nitrogen. At the same time it has relieved the world of the fear of a food shortage through the lack of nitrogen for fertilizer, which was predicted by Sir William Crookes in the late nineties—the price of nitrogen has been greatly reduced; and it has opened up still further complications with-

in the chemical industry itself. This point calls for elucidation and requires us to backtrack in a slightly different direction.

Effects of Cheap Material and New Equipment

It is characteristic of many chemical processes that a particular product is not manufactured without an accompanying product which may or may not be wanted. An example of such is the manufacture of caustic soda and chlorine from salt as the raw material. This customarily is done by the electrolysis of brine. At times the chlorine has been a drug on the market, as a result of the greater demand for the caustic soda. This was true until a short time ago when we began to develop new uses for chlorine. This gas has been used extensively for bleaching purposes; but recently more attention has been paid to the sterilization of domestic water by the use of chlorine and enormous quantities have gone into the chemical industry for the process known as chlorination, by which new solvents and other compounds have been prepared. The petroleum industry is using substantial quantities, and so the manufacturer began to wish he could make chlorine without caustic. Other new uses had been developed for caustic; for example—rayon, a newcomer, required very extensive quantities of it; but nevertheless the market was not well balanced between chlorine and caustic. Now, years and years ago it had been shown that if nitric acid were only cheap enough, salt could be treated with nitric acid; and by exercising considerable care in the control of the subsequent process, one might produce chlorine from the sodium chloride; and instead of having sodium caustic as a byproduct, find himself with a very salable grade of sodium nitrate. All this was recorded in the chemical literature, but there was no cheap nitric acid. For that matter, the fixation of atmospheric nitrogen, while providing a very convenient way for making nitric acid, did not reduce the price low enough for this particular use. It remained for new equipment to help accomplish that purpose; and this new equipment had to draw upon research in metallurgy, which gave our day and generation that remarkable alloy known as stainless steel.

Stainless steel, of which there are many varieties, provided it has the right percentage of chromium and of nickel, is not attacked by nitric acid, and the chemical engineer was quick to use this alloy to fashion a closed system in which the oxides of nitrogen could be delivered as nitric acid. Concurrent improvements in catalysts and in operating technique reduced the cost of fixed nitrogen and of nitric acid, and this very year a plant will be in operation manufacturing chlorine without caustic but with sodium nitrate useful in agriculture and other arts as the byproduct. This development is going forward in the plant of a company which produces synthetic ammonia from the nitrogen of the air and oxidizes it to nitric acid. This brings the other chlorine manufacturers face to face with a new phase in their own competition, and it gives an elasticity to production in this field which should be a stabilizer and balancing factor.

But this fixation of nitrogen did another thing. Until this method of making nitric acid among other nitrogen compounds became commercial, nitric acid was made by treating sodium nitrate with sulfuric acid. The sulfuric acid displaced the nitrate radical and appeared in the byproduct as sodium bisulfate or niter cake. This was used to make sodium sulfate or "salt cake" which found a ready demand in the manufacture of that variety of wood pulp known as kraft, out of which the strong heavy wrapping papers are made. The advantages of making nitric acid from ammonia were such that there was presently a shortage of what had but lately been a byproduct, and chemical manufacturers had to turn their attention to other ways of producing sodium sulfate for the paper industry. Indeed, and by a strange twist of circumstances, sodium sulfate is now produced in Chile to help fill a demand created when less Chilean nitrate was used for making nitric acid.

We have gone into considerable detail in the above discussion merely because from it one may obtain a fair idea of why the chemical industry is likely to be so subject to change, the extent of such changes, and their effect upon industries both related and unrelated.

Research is Characteristic of Chemical Industry

But the chemical industry does not frown upon its ever-changing nature. It recognizes that just so long as products lack perfection and people demand more and newer things, and scientists have the urge to know the why and wherefore as well as the behavior of matter, research will continue. It encourages this research. It supports it indeed with a generous hand, for from it have come the processes and the products which are the industry. It would heartily agree with Charles F. Kettering in his saying that "one of the research man's jobs is to keep you reasonably dissatisfied with what you have", because it realizes that at the same time the research laboratory may evolve those better things which the public wishes to acquire and that it is this flow of new ideas that underlies industrial progress.

We have another example of delayed accomplishment in a new optical material which was first suggested many years ago but which has only now been put upon the market. It is still available only in sec-

tions of a few square inches, but a way has been found to so imbed crystals in cellulose acetate as to produce a material which in sheet form polarizes light passing through it. The same result is accomplished by another process where thin crystals are formed directly on the glass.

One suggested use is in the windshields and automobile headlights, with the angles of the two so adjusted as to materially decrease glare. Of course if the sheets in the headlights are at right angles to those in the windshield, the headlights would not be seen at all and would appear merely as black spots. However, a gradation would be possible.

The chemical industry furthermore returns again and again to the problem that seemed attractive but which has resisted solution. Not infrequently one must await a new theory before returning to the attack. Quite often it is a matter of new reagents available in quantity and at an attractive price, which are necessary. And as illustrated by stainless steel, it may mean a special sort of equipment without which manufacture cannot be undertaken with profit. Of course all of this means rapid obsolescence throughout the chemical industry and one great unit of that industry has long frankly practiced the policy of so pricing new products as rapidly to charge off development and possible obsolescence. Their customers have not been adverse to such a policy, realizing that they are ultimately the beneficiaries of progress and that the earlier a piece of equipment or the cost of research and development may be wiped off the books, the earlier is it possible to perfect the next new or better product in which they will be directly interested. It is true that many pieces of chemical equipment have a very long life, but others wear out with great rapidity and still others stand to be replaced immediately when the next better piece of equipment makes its appearance. It is apparent therefore that those who build equipment for the industry must themselves rely upon their own research and that of others and play a very large part in such advancement as the chemical industry can make.

Being researchful, the chemical industry then seeks out what it can use wherever it can find it. Some of its equipment is made of ceramic material, such as vitrified clay and stoneware. This should be dense and so made as to raw materials and glaze and firing as to be accurate in dimensions, resistant to corrosions, and able to withstand reasonable mechanical shock. Moving parts such as in pumps are often made of the material. A recent advance in which vacuumized or deaired clays were used was important because it meant a denser body which was strong and resistant to corrosion and which produced serviceable material of much thinner cross section. With the advent of rubber latex as a new material for the industry, the electrodeposition of rubber on metal by a process quite similar to electroplating of one metal upon another was developed to the point where rubber-plated equipment is now a possibility. And this means the protection of intricate parts against the corroding influences of some gases and liquids. The metallurgist has not only contributed stainless steel but he has recognized the advantage of preparing metals of lower cost in which the strength of inexpensive, ordinary steel could be combined with the resistance to corrosion afforded by the newer alloys. We have become accustomed to clad metals. "Sheffield plate" is an example and "Alclad" in which an aluminum alloy is protected by extremely pure aluminum is another. Their manufacture has brought to the fore some very fine metallurgical work, for it has meant, in one of the manufacturing methods, rolling down from a duplex ingot a sheet with the protective coating on one side. One may now purchase stainless steel-clad steel, nickel-clad steel, steel clad with various alloys, platinum-clad nickel, and other combinations of useful metals.

The ceramist and metallurgist working together have provided glass-lined equipment, used extensively in the food and beverage industry, in dairies, and in the great pharmaceutical industry, and in many places in the chemical industry. Where glass itself must be used or where it offers an advantage, it has been made available in sizes and sections unknown a decade ago, and built for the most part out of borosilicate types which have low coefficients of expansion and which therefore resist successfully sudden and extreme changes of temperature and which also possess great strength and resistance to mechanical shock. Not only tanks but pipe lines and other glass equipment are now to be found in the industry. Processes for lining metal and other kinds of vessels with rubber have become highly developed. Methods for joining glass and metal are new and important developments. Mention has been made of the use of synthetic resins for linings and for tanks and vessels, but we should not overlook the major contributions of the steel industry in the form of enormous forgings of special alloys which form the reaction chambers for high-temperature and high-pressure work, notably in the fixation of atmospheric nitrogen and the hydrogenation of petroleum.

One of the important tendencies or trends in the chemical industry has been that from batch to continuous processes. This is one of America's signal contributions to the chemical industry. The continuous process requires a more complicated set of equipment and perhaps more careful supervision, but there is a saving in time, a more uniform product, and

smaller losses in production. By a careful choice of units, the production rate can be made very elastic.

Another more recent trend in common with certain other industries is that toward automatic control. Automatic control is not installed primarily to reduce the number of jobs. What it accomplishes principally is accuracy in operation, improved uniformity of product, and hence lower over-all cost. It achieves a higher quality and tends to increase the skill of the operator. It is vital to a continuous process and it rests for the most part on the ability to detect, by chemical or physical means, very small differences in such physical attributes as pressure, temperature, volume, density, weight, vapor pressure, magnetism, electrical resistance or conductivity, light intensity, color, thermal properties, relative humidity, and the like. Electrical and mechanical engineers working with chemists and chemical engineers have developed devices which after detecting these differences actuate mechanisms which in turn are able to correct for these variations. Thus there are devices which will proportion fluids or solids. There are those which will add or remove heat or will regulate the rate of flow; will automatically maintain a desired pressure or vacuum. They will adjust the composition. They will detect errors in wrapping and labeling or packaging. Indeed it is not generally realized how essential automatic control is to many operations nor what the trends are toward broader automatic control. In one chemical plant $500,000 is invested in control instruments. Extensive automatic control is found in plants distilling solvents, in refining petroleum products, in heat treating metals, and in power plants.

The perfection of automatic devices has gone far toward simplifying buildings in the industry. Formerly when the operator of, say, a distillation plant, was required to go from unit to unit to read pressure gages, thermometers, and flow-meters, and then adjust valves, it was customary to house the whole equipment. Nowadays the control panel with its actuating devices is all that need be put into one small air-conditioned, comfortable room and the remainder of the equipment in many parts of the country can be left to the elements, protected only by the resistant materials of which it is constructed and its insulation. This has given rise to a new type of architecture, upon many a landscape, and has served literally and figuratively to reduce the overhead that once appeared in brick and mortar, steel, and galvanized iron. One fair sized alcohol distillation plant operates with one man per shift.

The lag between discovery and use may be caused by a number of factors, among them, suitable structural materials, by awaiting cheaper raw materials or reagents, and by unexpected developments in consumer demand. Reference will be made to the second of these, but now consider what has happened in the case of bromine since its history is typical of the third factor.

Bromine From the Sea

Bromine is an element, a virtual monopoly of which was once exercised by the German chemical industry. At that time its principal use was in the manufacture of pharmaceuticals and photographic materials. A source of bromine was found in the brines from deep wells in Michigan and this was developed to the point where a considerable share of the world supply was obtained. There appeared to be sufficient bromine for all purposes until the unexpected discovery of a new use for tetraethyl lead put in its appearance. The demand which brought forth tetraethyl lead was for something which would so control detonation in the gasoline engine as to permit the use of higher compression ratios without the familiar knock in the engine. Of a large number of materials tried, tetraethyl lead gave the best results and in its use in motor fuels a compound of bromine is required. At first this merely constituted an acceptable new demand for a product, but it soon became evident that there was not enough bromine obtainable from the ordinary sources to supply this new requirement.

It was known that there is a small amount of bromine present in sea water, roughly 65 parts per million parts of water, but that is a very dilute solution and at first it seemed impracticable to handle so large a volume of water, even if most of the bromine could be separated in recoverable form. A series of experiments and developments, however, led to the perfection of a process in which the water comes in contact with the reagents for less than a minute and which has proved so successful commercially that during 1935 some 600,000 pounds of bromine per month were derived from the sea. The process recovers 60 of the 65 parts of bromine present per million parts of water, and involves good chemistry and chemical engineering. Unfortunately, gold is present in very much smaller quantity, perhaps 4 to 7 parts per billion, so that while a few milligrams of gold have been separated as a by-product of the bromine process, just to show that it can be done, it does not yet seem economically attractive. But who shall say but that in future a method may be developed that will make it practical and profitable to look to the sea as an additional source of gold?

The sea is, of course, a vast resource of many things. It is difficult to comprehend anything approaching its magnitude. We cannot calculate accurately the number of cubic miles in the sea, but Hendrik Willem Van Loon has said that all the peoples of the earth could be put into a box one-half mile in each dimension, and

an arithmetical calculation will show that with pumps running at the rate of 30,000 gallons per minute, it will take approximately 80 years to pump a cubic mile of water. These figures can do little more than serve to catalog the sea as well nigh inexhaustible. We have long utilized deposits of minerals left when the sea water evaporated, and now the Dead Sea is being processed for its content of chemical compounds. During the war the salts of the dry Searles Lake became an important source of potash in America, and on the west coast today there is another operation in progress which has for its object the separation of compounds of magnesium from the sea. During two and a half years of operation of the bromine plant to which reference has been made, potential byproducts not actually recovered included sodium chloride, magnesium sulfate, calcium chloride, potassium chloride, magnesium, aluminum, strontium carbonate, iron, copper, iodine, silver, and gold. It seems more than likely that in future we shall look more and more to this vast supply of compounds in solution as a source of needed chemical materials.

A Cheap Agricultural Product; An Important Raw Material

One of the great fermentation industries is founded on raw materials which are relatively cheap. In response to an insistent need of a foreign ally during the World War, there grew up in the Midwest a plant where off-grade corn, frequently a drug on the market, was the principal raw material for the manufacture of acetone by a fermentation process. Produced concurrently were alcohols, including butyl alcohol, for which, at the time, there was no use. It was fortunate that this was saved in huge tanks rather than discarded, for following the war it became a very important solvent in the manufacture of a lacquer which revolutionized the coating industry. As the price of corn shifted sometimes between wide limits, this organization constantly sought cheaper sources of fermentable sugars and now uses molasses. The materials must of necessity be cheap to maintain the industry.

Lacquer

The use of this butanol in the nitrocellulose type of lacquer is one of our best examples of how a new chemical compound can revolutionize an industry. Prior to its appearance a minimum of 26 days was required to finish a fine motor car, for the simple reason that paints and varnishes in use until that time dried slowly. Not only did this mean tying up large values in goods in process, but it was becoming difficult to obtain apprentices for the finishing trade, and to find housing where the work could be carried on without an inordinate investment in brick and mortar. The development of these cellulose lacquers changed the whole picture, and instead of days, hours were all that were needed to complete the job. The ease of application, the range of colors, the short drying time, the protection afforded, the resistance of the lacquer to cleansing agents, and its general service were factors in its rapid spread to other industries where metal and eventually wood were to be coated. The paint and varnish industry was obliged to add an entirely new category of lacquers to its stock in trade and to adjust itself to a new situation.

The lacquer industry has by no means stood still. In fact, it has been constantly changing with synthetic resins now making their way in competition with solutions of nitrocellulose and, with more recent applications of dispersing agents, with lower surface tension, there have even appeared lacquers in which the more expensive and inflammable solvents have been replaced to a considerable extent by water. This in turn has broadened their field and made possible the use of this type of lacquer for applications where absorption, as on a porous surface, must be accomplished. The water emulsions appear to be better for this use in a number of instances.

But this has not been the end of the story, for with these newer solvents coming from the fermentation industries, attention has been concentrated upon them and we find them now coming from petroleum, from the chlorination of fractions of natural gas, and from synthesis, in which gases are polymerized to form a never-ending list of new solvents for special uses. Indeed, whole new industries have sprung up and grown as a result of this advance, and it seems likely that the research worker will enable the production man to continue the program of devising solvents of special characteristics for specific uses. Further, nitrocellulose for lacquers is now being rapidly displaced by synthetic resins. Change characterizes the chemical industry.

Petroleum

Now let us consider quite briefly some of the typical chemical industries, beginning with petroleum. The time will come in our opinion (if indeed it is not already here) when we will bemoan the way in which our petroleum resources have been wasted. While much progress has been achieved in learning how to convert a larger percentage of crude petroleum into such useful things as gasoline and lubricating oils, unquestionably in the past there has been great waste of those fractions for which there was not then a market, and even today we continue to burn as fuel for internal-combustion motors highly complex mixtures of hydrocarbons. Today with all that is known about

lubrication there are many fundamentals which are not sufficiently understood to enable the best results to be obtained, and only in the past few years has new knowledge enabled us to make really substantial progress in the development of better lubricants. Distillation, cracking and the hydrogenation of petroleum have enabled considerable tailoring to be done on petroleum molecules, so they can well nigh be taken apart and put together again in accordance with specifications. Further progress in this may confidently be expected and with the work of separating the individual hydrocarbons found in petroleum it is not improbable that one of these days we may come to synthesize those which can be used with greatest efficiency in the internal-combustion engine. We now strive to get the largest possible proportion of serviceable energy by utilizing gasoline under the best conditions for the mixture. It is obvious if we could work with a single hydrocarbon or at the worst a comparatively simple mixture of hydrocarbons, there would be a far greater opportunity of maintaining conditions for combustion that would yield a much larger percentage of useful energy as the fuel is consumed. Notable progress has been made in developing inhibitors to gum formation and this line of work is quite likely to continue with some acceleration.

Within a year or two polymerization of refinery gases to produce a gasoline of high antiknock rating has become commercial. This is a commendable step in conservation and fortunately the gasoline so made by combining the smaller gas molecules into large gasoline-like molecules yields a fuel of such high antiknock qualities as to indicate its use in some of the lower-grade fuels for the benefit of both producer and consumer. We may expect to hear much more about polymer and polymerized gasoline in the future. It is gradually becoming recognized that the huge waste of natural gas in the oil fields must stop if for no other reason than because in addition to fuel value it is the source of many chemicals.

An indication of what might be expected in the field of fuels for internal-combustion motors is the recently announced blend of isopropyl ether with a small quantity of tetraethyllead, tentatively known as EL–435, which when blended in the ratio of 40 percent with 60 percent of ordinary aviation gasoline attains an antiknock rating of 100. It is quite likely even that figure will be exceeded in the future. With comparatively slight modifications the present engine blends will be able to effect a saving of approximately 15 percent in fuel consumption with a corresponding increase in pay load or gain in power of up to 30 percent. In the case of trans-Atlantic service and other long-distance flying, such a margin may mean the difference between success and failure. It will be noted, however, that this is one of the trends toward the preparation of a definite chemical compound instead of a mixture for internal combustion motors. There is said to be sufficient propylene, which is the raw material for this compound, available in the United States to produce up to 850,000,000 gallons annually of a blended aviation gasoline. This is nearly 10 times the present annual fuel consumption of all aircraft in the country.

In lubricants the success in refining by solvent and similar methods, in producing an oil as pure as possible, has opened up some new problems, including the question of whether these oils do not naturally contain a corrosion inhibitor, a part of which should be in the final product. With the petroleum industry tending so definitely in the direction of chemical manufacture, we may expect simpler mixtures in efficient lubricants as well as in fuels.

A newcomer in the field of lubrication is an oil in which great film strength is achieved by mixing 1 percent of one of the compounds of phosphorus in 99 percent petroleum oil. In a test, stock cars using it for 100,000 miles showed less wear than normally occurs in 10,000 miles of service. If it realizes expectations, such an oil would materially lessen the national cost of motor upkeep.

A considerable beginning has been made in the utilization of petroleum as a raw material in the manufacture of important chemicals. Large tonnages of alcohol are being produced from ethylene at a cost estimated to be less than by the fermentation of carbohydrates. Acetone is another chemical economically produced from petroleum. Amyl alcohol from pentane derived from petroleum is another, and acetylene is being produced from the gas methane. Ethylene glycol has become an important chemical of petroleum ancestry and even a synthetic plastic is now prepared from petroleum residues.

There are so many people employed in the petroleum industry that any circumstance that might seriously disturb that industry is of social importance. What would happen if our supply of crude petroleum should suddenly dwindle? Perhaps it is fair to assume that maintaining a large sales organization, the petroleum industry would continue to prepare and market whatever fuels might be available. There are already in use in many parts of the world blends of gasoline with alcohol, for the most part required in those countries to assist agriculture. The alcohol is readily prepared from annual growing farm crops. The relative costs of alcohol and gasoline make the proposal economically unattractive at the present time in the United States, and wide interest can scarcely be expected until the cost curves of the two materials at least approach, if they do not actually cross each other. If, as, and when, the United States

should embark on a large-scale program for the use of alcohol in a motor fuel, estimates indicate that thousands of acres would be required to grow the raw material for fermentation, a large number of alcohol distilleries would be required, and many hundreds of men would find new employment. The fuel distribution system would not be disturbed, but to what extent those now employed in oil fields, oil refineries, and kindred services would be displaced has not been estimated. The alcohol advocates would contend, however, that when crude oil becomes less plentiful these employees would face loss of position anyway. From present data it would seem certain that large-scale agriculture undertaken to support the fuel alcohol industry would need to be conducted on the basis of producing the utmost at the lowest possible unit price, rather than to practice any program of restriction.

In the meantime abroad the hydrogenation of coal tars has reached substantial proportions. In Germany between 900,000 and 1,000,000 metric tons of a fuel satisfactory for automobile-type engines is being produced by adding the gas hydrogen to these coal tars or to powdered coal in a stream of crude oil at elevated temperature and high pressure. The same process or a modification of it has been subsidized in Great Britain. Besides the possibility of our applying a similar process to the bituminous coal and tars made therefrom, in this country, the research on hydrogenation has been extended by one of the great oil companies of the United States which at great expense has learned how the method can be so modified as to apply to petroleum hydrocarbons. The statement has been made that if it were economically attractive to do so, which means the use of other sources of power for refinery operations, it would be possible by combining what is already known of distillation, cracking, and hydrogenation to produce 105 barrels of gasoline from 100 barrels of petroleum, which is a very much greater yield than is obtained without hydrogenation. The wider use of this combination of steps would seem to make possible greatly to prolong the time during which gasoline as we now know it would be available, and lessen materially the insistent necessity for the discovery of new crude oil resources.

Opinions differ as to when oil shales may become economically important. Their use may be more feasible than to blend alcohol with gasoline but their distance from consuming centers, the heat and power required to process them, and the more attractive coal hydrogenation possibilities are factors in the equation.

Fuels

The world having used wastefully great stores of fuels, science at last is being applied to the question of using them with a view to making the most of their various values. While there is still waste, we can be encouraged by increases in efficiency which now give more energy for actual use per pound of fuel than heretofore, by mechanical inventions which extend the range of useful fuels to include those of lower rank and by efforts to so treat various fuels as to secure whatever chemical values they may possess before conveying the residue to the fire.

The manufacture of polymerized gasoline from refinery gases, the hydrogenation of the tars and coals to produce liquid fuels, the efficiency gained with powdered coal, the effort to prepare a coke suitable for household use without the dust and smoke of coal and at the same time recover from the coal that is coked by products of economic value—all indicate trends in fuel technology that depend for their furtherance upon the application of science.

One of the problems in the use of powdered fuel is the disposition of fly ash. This is a material very difficult to manage, quite objectionable in the atmosphere and produced in large quantities in great power plants. Some experiments in the use of fly ash in producing building blocks, as a filler, etc., have progressed, but the invention of some product easy to manufacture and widely used with fly ash as the raw material will certainly encourage the more extensive burning of powdered coal, with concurrent lessening of the smoke nuisances from factories, and with increased efficiency in the power plant.

The possibility of so blending coals of different rank and characteristics as to make more satisfactory fuel, the methods for the separation of ash producing materials from the coal prior to burning, the improvements in the storage and distribution of gas from coal are other indications.

Within the last decade an entirely new type of fuel has made its appearance in the domestic market. This is liquefied petroleum gases, usually propane, butane, or mixtures of the two, while of late pentane has entered the field. These gases in cylinders with suitable reducing valves and safety devices are in growing use in rural districts and make available to them such advantages as heretofore have been confined to those communities where gas has been manufactured from coal or where natural gas has been available. In some communities these liquefied petroleum gases are received in tank cars, are expanded in suitable gas holders, adjusted to give the heating value expected of such gas, and then piped over limited distances for household service. These gases also have an industrial use for some special applications.

Recent statistics from the United States Bureau of Mines indicate steady growth in the consumption of liquefied petroleum gases. In 1935, 34,655,000 gallons

of propane, 34,084,000 gallons of butane, 5,651,000 gallons of mixed gases, and 2,465,000 gallons of pentane were supplied in this form.

The results should include a material prolongation of the period during which our fuel resources will serve, together with an improvement in economy which should at least prevent excessive price rise which otherwise might be concurrent with increased demand and consumption as time goes on. Most of our fuel resources are from irreplaceable natural deposits and science and technology would seem to have their work cut out for them to prolong for an appreciable period the time during which fuels as we known them will be available.

Fertilizers

From the standpoint of national planning there are few chemical subjects more important than fertilizers. Broadly speaking, agriculture is well nigh the only remaining industry capable of absorbing the activities of sufficient numbers of Americans to take care of unemployment. Since apparently industry cannot do so, the alternatives appear to be either to shift the population into agricultural pursuits where they may be self-sustaining to a degree, passing on less of a burden to the others, or else frankly to put them on relief. If the former is chosen, then agriculture must be maintained on a small-farm individualistic basis and to achieve this it becomes necessary that farm life be made as attractive and as easy as possible. To this end cheap fertilizers assume great importance and relating as it does to our food supply, the fertilizer industry in addition is of profound interest in its social implications.

While the application of chemistry to crop production is still less than 100 years old, the fertilizer industry as now constituted is quite old as years are reckoned in chemical industry. In fact, to its antiquity may be ascribed responsibility for the antiquated practices which still persist, as likewise for present distinct trends toward a new order. Chemical industry is universally characterized by rapid change, by which token the fertilizer industry is overripe for a complete rehabilitation. The earlier conception of the role of fertilizers as being that of making "two blades of grass grow where only one grew before" has given way to the more modern understanding of their function as being to make a crop yield $2 where only one was yielded before.

The rapidly accumulating evidence of soil depletion over wide agricultural areas, the reduction in crop yields on improperly fertilized or unfertilized areas and on others, the reduction of fertility levels to the point where fertilizer applications represent the minimum subsistence diet, combined with an aroused public consciousness of the importance of soil fertility conservation and restoration, will inevitably lead to a demand that the chemical industry provide here the same high order of service which it offers elsewhere in meeting man's aspirations for more abundance and greater efficiency.

The present fertilizer industry grew up around the acidulation of phosphate rock, practically the only chemical operation employed therein. The product was acid phosphate containing some 16 percent P_2O_5, to which, in the earlier days were added small quantities of nitrogen carriers, such as guano, slaughterhouse tankage, garbage tankage, fish scrap, and low-analysis potash salts of foreign origin, to be replaced gradually in subsequent years by the higher grades of nitrogen carriers, ammonium sulfate and sodium nitrate, for years likewise largely of foreign origin, and the more concentrated potash salts. With this transition the fertilizer industry found itself the manufacturer of only one of three essential ingredients. The abundance of phosphate deposits contiguous to agricultural areas led to an overexpansion in the production of phosphates and the sale of the surplus beyond the producer's requirements. Thus there appeared on the market all three of the conventional fertilizer ingredients which led to the development of the so-called dry-mixing industry, a term which differentiates between those who manufacture their own phosphates (wet-mixtures), purchasing their nitrogen and potash requirements and those who purchase all three. Of the 968 production units registered, 772 fall within the latter category, leaving 196 as the number of fertilizer manufacturers who employ the very simple chemical operation of applying sulfuric acid to ground phosphate rock. From that point on, the industry confines itself to the mixing of the three ingredients in varying proportions and distributing the product. This mixing operation is of such extreme simplicity as to invite the entrance into the industry of anyone aspiring to become a fertilizer "manufacturer." Relieved of the various corporate charges incurred by the larger units, these minor units offer a formidable type of competition. In the past, various States on occasions have advised the farmer to do his own mixing, and the activities of the farmers' cooperatives in this field have shown marked increases.

However, the habits formed during the era when only low-grade ingredients were available, resulting in low-analysis mixtures, have persisted very largely up to the present time, although highly concentrated ingredients are readily available and the economies from their use in less diluted mixtures are widely known. Trade demand, the result of earlier teachings, is offered as the reason for the perpetuation of this wasteful practice.

The fertilizer industry has been beset by a number of difficulties growing out of methods of financing, out of a self-imposed multiplicity of brands and trademarked names—which have really meant nothing and which, happily, are now being abandoned—and, in certain important consumer territories, out of the fact that fertilizers are still being purchased by the ton, all too frequently with little or no regard to composition. It will be seen that the psychology of the large package enters at once into the problem, particularly so where the intellectual or economic level of the consumer places him beyond the effective reach of the State agricultural advisers, constantly teaching that plant food costs more in the low-grade mixtures. The price per ton, not the price per unit of plant food, is the dominant factor, a situation in which the dealer's commission payable on a tonnage basis probably fails to operate as a corrective influence.

The major fertilizer ingredients in current use carry their own unavoidable diluents. Superphosphate, to start with, contains equal parts of monocalcium phosfate and calcium sulfate. The agronomic value of the latter ingredient, when used in such large proportions as enter the low-grade mixtures, is being seriously questioned even by the industry itself. Of the phosphatic ingredient, the plant food is reckoned as P_2O_5, of which the mixture, as a whole, contains 16 to 20 percent, the concomitant diluents thus amounting to 80–84 percent. Likewise, sodium nitrate and ammonium sulfate, with plant-food contents of 16 and 20 percent, carry diluents of 80 and 84 percent, respectively. Of potash salts, even the 60-percent (K_2O) muriate, approaching 100-percent KCl, still carries its burden of chlorine, while the lower grades contain sodium chloride in addition.

Even with these high-grade materials, as compared with those originally used, this unavoidable dilution would appear to suffice. On the contrary, further dilution is resorted to in the use of fillers, a practice which has led to the payment of vast sums by the agricultural industry for worthless materials. In a study of this question, Dr. A. L. Mehring, of the United States Department of Agriculture, has compiled data which indicate how large this expense has been. (See Yearbook of Commercial Fertilizer for 1934 and 1936.) The data show that in the year ended June 30, 1934, the farmers of Alabama, Florida, Virginia, Mississippi, North and South Carolina, and Georgia paid $5,482,227 for filler in mixed fertilizer.

The economic ills resulting from low-grade fertilizers are not confined to the matter of fillers, but include distribution charges, since freight is charged against gross weight, not quality, and, therefore, increases progressively as plant-food content decreases. The same applies to sacking, warehousing, selling costs, and the tag-tax paid the respective States on the tonnage basis. There results, therefore, a dissipation of the farmer's purchasing power in various collateral charges with a corresponding loss to the industry whose business, after all, is the distribution of plant food. Fluctuations in sales volumes of the fertilizer industry tend to parallel those of farm income, showing clearly that the farmer buys plant food when income permits. This meager surplus, set aside for plant-food purchase, should accrue to the industry rather than being dissipated among the various disproportionate charges entered against the low-grade products.

The subject of chemistry in the fertilizer industry properly, should not be restricted to superphosphate manufacture, since, after all, that is only one part of the industry, nitrogen and potash rapidly acquiring positions of equal importance. We have already reviewed briefly the amazing transformations that have taken place recently within the nitrogen industry which, at least during periods of peace, finds its major purpose in the service of agriculture. Within this industry research is given full play and the new products resulting, it will be observed, reflect the present trend toward high analysis. Beginning with the familiar products, ammonium sulfate, sodium nitrate, and cyanamid, there have followed liquid ammonia, a highly concentrated plant food used for the neutralization of acid phosphate and in turn, for the same purpose, that product carrying in solution urea or ammonium nitrate. Now granular urea makes its appearance on the market.

Within the potash industry chemistry has registered marked progress both in the refining of the subterranean salts and in that much more complex problem of separating potassium salts from the highly complex natural brines. Merchantable byproducts of increasing number and value have not only resulted, but the potash itself has been of progressively increasing purity. Potassium chloride, the major salt employed in fertilizers, is now abundantly available at 98 percent purity.

Saline combinations of two plant foods, such as potassium nitrate and ammonium phosphate are already familiar commodities, while within the laboratory there remain various others awaiting their commercial development.

From such materials fertilizers of almost any desired concentration can now be prepared, and by contrast with the antiquated, iniquitous, and in some States outlawed mixtures containing only 14 percent plant food, large tonnages containing 40 percent and considerable tonnages of 60 percent mixtures are currently sold.

Chemical research applied in the nitrogen and potash branches of the fertilizer industry has resulted in drastic reductions in prices of the respective products justifying on an economic, as long justified on an agronomic basis, their inclusion in more liberal ratios in fertilizer mixtures as the only way in which the farmer may share in the benefits of this great technological progress. Whether or not equal advances in phosphate technology are possible will be determined when some other method than the present sulfuric acid process has been perfected. Currently there is some interest in finding a suitable organic phosphate which would be soluble, thus making all the phosphoric acid available. To date the difficulty is to find an organic base that is both cheap and acceptable. In the phosphate industry's heavy investment in sulfuric acid plants may be found the reason why chemical research directed at their obsolescence is not being more actively prosecuted. Ultimately, it may be expected, dissatisfaction with a low grade phosphate carrier with its high distribution costs will lead to the further insistence that a new technology be developed. Surely chemical research effective elsewhere should not fail in improving a technology which has remained essentially stationary since J. B. Lawes first put sulfuric acid on bones in 1842.

It is not immediately apparent that there is anything more than historical significance in the fact that the fertilizer industry is centered around phosphates rather than nitrogen or potash. Perhaps its complete decentralization in that respect, as present trends would indicate, might remove some of the handicaps now being endured.

In addition to technology, chemical research is widely applied to fertilizer usage designed to improve both quality and benefit. This research extends to the soil and to the crops grown thereon. As stated, the low-grade mixtures in wide use are composed preponderantly of materials of little or no plant-food value. Inevitably questions have arisen as to the after-effects of these nonassimilated residues with answers revealing that some of them release acids in cumulative concentrations above the limits of tolerance. This has led to the formulation of nonacid-forming mixtures, as likewise to the increasing use of limestone or dolomite as corrective ingredients—"fillers" used for a purpose other than increasing bulk.

The optimum placement of fertilizers with respect to the root system of the crop which they are to nourish has been determined as a factor of major importance and has resulted, through collaboration with the engineer, in mechanical fertilizer drills whose use greatly increases the effectiveness of the fertilizer applied.

The occasional failure of crop response to adequate application of nitrogen, phosphorus and potash has led to chemical research extending the list of other elements essential to plant growth in which the infrequent soil is deficient, to include, in addition to calcium, magnesium, and sulfur, such "trace-elements" as boron, copper, manganese, and zinc. The soil chemist and the agronomist collaborating in this important field of research, while recognizing these and possibly other elements where absent as limiting factors in crop production, wisely refrain from recommending fertilizers that are formulated after the manner of patent medicines as cure-alls, but instead advise that the soil be studied from the viewpoint of what it contains and what it needs as required by the crop to be grown thereon. It is realized that phosphates containing all the elements of the original rock may carry "impurities" that are essential to plant growth. A "C. P." chemical may actually be unsuited to use as a fertilizer.

Soil Testing

To this end they have devised empirical "quick-test" methods wherein familiar chemical reactions are induced to yield color tints or turbidities, which, when compared with a chart correlated with soil type and crop response, in the hands of the experienced give clear indications of the available plant food present in the soil undergoing the test. These methods, requiring only a few minutes per determination, now winning wide acceptance, are the chemist's new contribution following the agronomist's complete rejection of the earlier total analysis of soils as failing to show any bearing on crop response and therefore on plant-food availability. The requirement was for a method which would indicate the plant food available for a given crop for a given season, not what might become available through little understood, natural agencies within unlimited time. The chemist has met the requirement with the result that the experienced interpreter may now prescribe with fair accuracy the plant foods that must be added to those already present in available form to yield the crop in quantity and of quality demanded by the grower. Likewise "tissue-tests", applied to plant juices and correlated with various abnormalities of growth or appearance, reveal plant-food deficiencies frequently early enough in the life of the growing crop to make possible their replenishment before irreparable damage has been done.

This new approach is already influencing certain units within the fertilizer industry to offer consumer service, instead of mere tonnage, providing the farmer with the plant food required by crop expectancy as

related to the soil and even the field on which grown. This may have far-reaching significance, for one of two roads appears as the choice of the industry: Shall a few mixtures be standardized to meet the broader requirements of agriculture or shall each crop be nurtured in terms of its individual preferences and the characteristics of the soil on which grown? Crop standards in terms of the various qualities on which market price is based would appear to determine the answer. The modern farmer demands quality as well as quantity, and the proper crop diet determines both.

The food value of the crop as influenced by its fertilization has not been neglected by the chemist who in collaboration with the animal nutritionist has traced the dietary benefits from the well-fed crop, linking therewith the health and performance of the animal organisms fed thereon, even to their progeny.

Soil Deficiency

How rapidly steps will be taken to deal adequately with the Nation's problem of soil deficiency it is difficult to say. Recent summations of current plant-food losses from the Nation's soils reveal such vast figures as clearly to indicate that the most that can be hoped for is to arrest the disintegration process. But even for the much simpler task of maintaining the better soils in their present state of productivity, there is clearly demanded a larger program of soil analysis revealing the supply of the essential elements present in available form and greater cooperation between farmer, the field service and extension men, and the fertilizer industry than has existed so far in correcting deficiencies.

Philosophical speculation has often led into visionary fields where crops, scientifically fed without fear of costs yield bounteously with minimum of labor, yielding happiness as the result of abundance.

The scientist has accepted this dream as within the purview of attainment. While realization is still too far distant for an appraisal of results, his faith must be strong indeed if he is to retain his courage in the presence of distress, not happiness growing out of overproduction, so easily confused in the popular mind with overabundance; hunger in the midst of plenty; populations in poverty because their farms can no longer yield a livelihood and vast areas formerly productive, now appraised as below the level of agricultural classification. He must be appalled when asked: Why fertilizer, when there is already a surplus? A question too often repeated by those who should know better. Again, he must feel that his efforts are futile when he observes that areas are classed as submarginal when he knows that all that is required is the application of a little more of the type of scientific agriculture which he is trying to teach. Perhaps he feels that national economy in such instances is better served by bringing back to the soil the plant food exhausted by faulty practices, than by uprooting the farmer and moving him to more fertile soils, to repeat the process of denudation.

To be sure, there are vast acreages bordering the semiarid areas which never should have been applied to crop growing, at least until the uncultivated lands of the humid regions, already provided with natural and social facilities for a more comfortable existence, had been more fully utilized. Within the latter is space enough, under a rational land policy, for all of those now in distress, for again we must remember that our agricultural practices taken as a whole are of the most desultory character. We pride ourselves on broad acreages and the physical prowess required for their cultivation, while by standards established by other nations of considerably more agricultural experience than we have, our yields per acre are certainly not praiseworthy. By the criterion of fertilizer use alone, a fairly safe one since wherever in these older European countries fertilizers are employed, their use is based on the profits realized, the United States is fifteenth in a list headed by Holland, applying plant food to crop and pasture lands at the average rate of 106 pounds per acre, as compared with our 4 pounds. The explanation is that fertilizer use is largely confined to the more eastern and southern States which are more accessible to sources of plant-food supply, indicating some relationship to fertilizer distribution costs.

The Nation's annual consumption of plant foods (nitrogen, phosphorus, and potassium) removed from the soil by harvested crops alone amounts to 8,494,528 tons. Perhaps it is this obvious inadequacy of the fertilizer industry in its present stage of development that has delayed up to the current year the inclusion of fertilizers among the agricultural relief agencies to be promoted by governmental bounty.

Industry, however, may be directly influenced in its trends by economic programs such as the new soil-conservation plan recently enacted by Congress, whereby payments are to be made to farmers who carry out certain soil-building and soil-conserving practices. In many regions benefit payments to be made to those sowing such soil-conserving crops as perennial grasses, relate to crops which can receive the fertilizer to be applied at a time other than the spring, which has always been the peak season for the fertilizer industry. If the practice becomes established and fairly widespread, it may do much toward leveling off the peaks and filling the valleys of the production curve of the industry and so far as manufacturing and mixing are concerned, make these operations more of a

year-round activity. Labor would be included among the beneficiaries.

In response to man's dreams, during the earlier years of scarcity, of more abundant plant-food supplies as the surest guarantee against hunger among rapidly increasing populations, the nitrogen of the atmosphere is at our disposal, vast phosphate deposits have been surveyed, although they remain untouched, and great accumulations of soluble potash salts have been made available in many parts of the world. The United States is unique among the major agricultural nations in possessing all three resources within her own borders. Yet our soils are being cast upon the dump heap of national inefficiency and even where in the growing of cash crops, fertilizer use has been accepted as the alternative to abandonment, in too many instances only the barest subsistence diet is provided, and the "crumbs from the table" of the cash crop are scavenged by the crop to follow if there is a rotation.

Chemical technology here is confronted by a field of endeavor which, if judged by the tasks that lie ahead, may be said to be largely untouched. In its social implications, no technological problem possesses greater opportunity for service than that of arresting the decadence of the Nation's soils. Less remotely, there is the pressing task of contributing to the solution of agriculture's more immediate problems, to the extent at least of substituting science for sweat in the growing of crops. Raw materials are at hand, trained technologists await the task. Elsewhere must be found the reason why the American fertilizer industry still supplies only 4 pounds of plant food per acre.

Cellulose

Cellulose and the industries dependent upon it as a raw material afford one of the most interesting fields in the modern chemical industry. This compound, the molecular structure of which is still not definitely determined, has long been the basis of such important industries as textiles, paper, and lumber, and has supplied the raw material for pyroxylin, still the cheapest of plastics, gun cotton, and perhaps one or two other industries. In the last little while there has been added to this list artificial leather, film for photographic and other purposes, toilet articles, Cellophane, Sylphrap, Kodapak, and similar wrapping materials, lacquers of cotton or other cellulose base, and the amazing chemical fiber or rayon industry.

It seems certain, however, that notwithstanding the tremendous advances made in all of these and other cellulose lines in the last generation, we confront not only the possibility but the likelihood that there will be extensive changes in direct proportion as our knowledge of cellulose expands. For instance, today cellulose acetate is the chemical composition of the fiber preferred for many types of textiles, while regenerated cellulose or the product of the viscose industry and known as rayon makes up the great bulk of hundreds of millions of pounds now produced annually. Cellulose acetate has entered the plastics field, but it is recognized that for many of the purposes cellulose nitrate would be the ideal material but for its flammability. Research is actively in progress in many quarters, looking to the perfection of better cellulose compounds for these special applications. Cellulose acetate has been mentioned. Cellulose propionate has some superior characteristics and its commercial production awaits only the availability of less-expensive propionic acid. Cellulose ethers would be better still for some uses and will undoubtedly be commercially available before so very long.

It has already been determined that the chemical and physical properties of some cellulose products depend directly upon characteristics within the raw material, whether it come from cotton or from wood, prior to processing. It is conceived that the fiber as it is produced naturally in the cotton plant or the tree is made up of many ultimate units, held together by some adhesive like lignin and if in place of these, commercial steps could be developed whereby a chemical bond could replace this physical adhesion, the result would be a stronger fiber with greater service life. Just what the influence of such a process would be on the many industries dependent upon cellulose is difficult to forecast. Increased durability might tend to decrease annual production in established fields but on the other hand there might be a number of new uses which cannot be attempted until this step has been achieved. In this connection should be mentioned the possibility of simplifying textile manufacture by substituting some chemical adhesion for twisting threads and weaving them.

One of the most interesting developments at the moment is the keen competition between wood and cotton as a source of raw material. The producers of cotton seem to have assumed that no other source of cellulose could compete with the cotton fiber, but that has not proved to be the case. Perhaps a realization that substantial improvements in fiber from wood were necessary if it were to compete with cotton has been one urge for research in the field. But the result is that alpha-cellulose from wood, besides being much cheaper, is now preferred for some uses, and unless something can be done to improve the cellulose available from cotton linters, so that it holds its place in quality while at the same time becoming less costly, that source is likely to suffer materially through decreased demand. Many efforts have been made and continue to be made to use cellulose from cornstalks, from sugarcane, and elsewhere, but costs of collection

and processing, the fact that annual crops must be gathered and stored, and the advantage of cellulose concentration in wood, make it difficult for these other plants to compete.

One method of attack is that proposed by Frank K. Cameron, of the University of North Carolina, who proposes that cotton be grown thick in the field, forcing the largest possible number of bolls to mature at the same time, and then treat the whole crop as one might harvest hay. After drying and powdering, chemical treatments would first extract the oil and then convert the cotton fiber and the cellulose of the cotton plant into alpha-cellulose, which is desired by the cellulose industry. Should this proposal prove to be practicable, its social implications might be of great moment because of its direct effect upon the cotton farmer and the cotton picker.

A good example of how developments in one field affect others is to be found in paper containers for fluids and liquids. This is a problem of long standing but only in the last year or two has the result been widely felt. Now oil, milk, and the like are offered in paper containers designed for onetime use. The potential market for such containers is such as to raise the question of adequate supplies of paraffin which would be required, while the competition with glass has already given rise to some peculiar situations. Thanks to the perfection of mechanical glass-blowing, milk bottles have reached a very economic production cost. But there are other factors in the use of the milk bottle. For example, the used bottles must be gathered and cleansed for reuse. So many bottles are broken or lost that retailers frequently require a deposit against their safe return. All this is unnecessary in the case of the paper container, and many distributors of milk find their use less expensive, all factors considered, than glass. However, control officials in some States have looked upon the paper container as offering unfair competition and have undertaken to require a higher price to be paid for milk of the same quality when delivered in paper as compared with glass. However absurd these requirements may seem, they are probably the reflection of a competitive situation that may become severe and into which it is not unlikely that politics may enter. It is to be hoped, however, that ultimately any economies and conveniences in distribution that may be secured in this way may be realized by the ultimate consumer.

Undoubtedly many new sources will be sought, and there are now ready for commercial exploitation new and improved processes for the use of southern woods, heretofore regarded as unsuitable for chemical purposes. These include varieties of pine, cypress, and gum. Agriculture, in which corn might be grown between rows of growing trees, with younger trees as material for paper pulp, naval stores, and then lumbering, offers, in combination, a number of activities that might easily give rise to new industries in the South to compete with paper makers in the North where the growth of trees is very much slower. With all ordinary agricultural crops left out of consideration, the cycle is 20 years. Notwithstanding the advantages, they seem to lack attractiveness for established mills which in addition to investment in plant and machinery, workmen's houses, and the like, control such areas of timber land and engage in reforestation on a scale such that ample supplies of wood seem assured practically in perpetuity. However, several new pulp and paper mills are being erected in the South, and the ultimate effects will surely include some obsolescence of northern and Canadian mills. In several countries where wood is scarce and straws are plentiful, pulp is being made from them by a chlorine process for use alone or with other fibers. A plant for making high-grade straw pulp is ready to operate here whenever economies make it advantageous.

Kraft is the name given to strong paper of various colors, usually a shade of brown, familiar as wrapping. The perfection of a white kraft with the strength possessed by the well-known variety would certainly increase the competition between paper and paper-like materials and textiles. Another development is the use of lacquer on paper rather than the usual coatings, for these lacquers give not only strength but improved appearance. They may eventually make an unmistakable impress upon the casein market, certain types of clays and chemicals used as coating materials, and influence somewhat the manufacture of printing inks. Paper impregnated and coated with tung-oil preparations has been put to use in Japan for emergency raincoats. Cord of wood cellulose already competes with "string" made from the usual fibers.

It must be borne in mind that chemical industries depending upon cellulose are already great in extent, that the products are to be met in all sorts of manufacturing, in structural materials, textiles, etc., and that nothwithstanding what has taken place it is generally agreed that it is only the beginning. It is a conspicuous example of a case where further progress will not be spectacular until the fundamental work on the molecule (in this case cellulose) has reached a place where the information can be utilized in industry itself.

A word should be added regarding lignin, a by-product of the cellulose industry, in the use of which there is a rapidly growing development. It is the lignin compounds which for years have been polluting

our streams. Lignin, among other things, is a coming plastic, not only as such but in combination with other materials. It may well be the basis of important industrial developments if not new industries.

Coated Fabrics

Closely allied with the cellulose industry is that of coated fabrics, of which millions of yards are produced annually. While originally coated with compounds involving vegetable oils like linseed in the manufacture of linoleum, oilcloth, and the like, we now have a much greater variety of these useful materials in the manufacture of many of which we find combined impregnation with the coating operation. To the several drying oils that may still be used have been added solutions of nitrocellulose, as in the manufacture of artificial leather and latex, which is the sap of the rubber tree. Improved methods for embossing, for applying designs in other ways such as printing, top coatings which better resist moisture and cleansing agents, and give increase in wear, anti-oxidants and plasticisers, compounds that are nearly odorless, all of these improvements have met a widely expanding field with rapidly increased production in normal times. True, a part of the market is lost when the price of some grades of leather falls; a factor is the change in the manufacture of automobiles, the decided trend toward closed models having eliminated many tops and now the all-steel bodies are taking even that small part of the old market left for the small patch on the older type top. But newer uses have had to be found with the result that these fabrics find their domestic uses from table linen to bath curtains and rainproofs and some of these synthetic leathers are finding their way into serviceable wear in certain types of shoes. While the industry as a whole may not increase rapidly in the immediate future, it seems reasonable to prophesy that competition offered by coated and impregnated fabrics will be found in an increasing number of fields.

Insulation

Insulation other than electrical, in which we include not only efforts to control heat transfer but also sound, is a comparatively recent industry. Asbestos, diatomaceous earth, and rock wool are types of materials that have been used extensively in industry but of late the insulation of homes and office buildings, the protection of pipe lines and storage tanks, and the effort generally to prevent too wide a variation in temperature, has brought to the fore a number of other materials. Here and there slag is now being fluxed to the point where the molten stream meeting a high pressure jet of air or steam is blown into a long cooling chamber out of which it comes as a fibrous material to be worked in a variety of ways for insulating purposes. Corncobs have been ground and used in a similar fashion, particularly blown into interstices between the walls of homes and other buildings. A variety including nearly all of the lighter-weight materials possessing the necessary chemical and physical characteristics has been used for such work and the market is not yet fully satisfied.

The latest comer in the field is glass, now produced in fibers between 0.000020 and 0.000025 inch in diameter, which can be used very much as vegetable or animal fibers might be employed, whether as pads or spun into thread and woven. Glass blocks and now a special type of window glass consisting of two sheets so put together as to provide a dead air space, make their appearance to assist in insulation.

Fiberboards, from paperlike materials to highly specialized products from cornstalks, types of straw, bagasse, or paper pulp, are widely employed offering in addition to their service as insulators considerable competition for the lumber industry, since some of these products are produced in a dense form to replace lumber.

Air conditioning, the urge to economize in fuels and the realization that city noise is something with which we must cope, would indicate that insulation will be in continued demand and the trend is toward nonflammable nonpacking materials of low specific gravity, which can be produced at a price the consumer will pay. To date glass is the newest competitor.

Water Treatment and Sewage Disposal

Water treatment and sewage disposal are somewhat related and are almost equally important as the concentration of population increases. The industrial requirements have become such that water treatment for this purpose, not to mention domestic supplies, has received increasing attention. Odor and color can usually be eliminated, while improvements in methods of sterilization have somewhat broadened the choice of sources as to water supply. There is a growing tendency toward not only preparing water to meet a given set of industrial conditions, but to require that industry so to treat its wastes as to return to the streams water which will be useful to other industries and for other purposes. Some States have been so progressive as to attempt zoning of streams for specified uses, and of late there has been some agitation to turn over the whole matter of water control to the Federal Government. This proposal has met with many objections, the preference being to leave the management of so important a resource in the hands of the several States.

The special chemical contributions include chlorine in its various forms for sterilization of water supplies.

the colloidal silver treatment of more limited application, the use of activated carbon for absorption purposes with special reference to color and odors, the artificial and prepared natural zeolites for water softening, and anaerobic fermentation in the treatment of sewage. Water-softening chemicals and the base-exchange materials such as the zeolites are used on a large scale not only for industry but for domestic supplies, involving the treatment of water for a whole municipality down to individual household units.

The possible effect of stream and flood control on the volume of water in rivers of industrial importance, is obvious. The cost of reducing industrial waste so that the effluent of a plant will be as desirable for other uses as the water entering the plant is such under present methods as to make the industrial operation unattractive. However, even now this is a pressing problem in many localities, and inexpensive waste treatment and sewage disposal continue to engage attention of many research workers.

Not only is the trend toward abatement of the pollution of water supplies, but also the pollution of the atmosphere which is a serious matter in certain types of industrial districts. However, industry alone cannot be charged with all the guilt, since where smoke, soot, and chemical compounds resulting from burning raw fuel are concerned, the domestic heating plant in the aggregate is a greater offender. The type of plant, the inexperience of the operator, and popular opinion, make it difficult to exercise any rigid control, hence the importance of research on the fuels themselves, and on coke and gas for domestic consumption.

Rubber

The present trends in rubber and the great rubber-products industry are toward new uses for rubber and the development of synthetic rubberlike materials including plastics. When it was discovered that by the use of ammonia, latex from the rubber tree could be brought to the factory in Europe or America practically unchanged, a material was made available for industrial processes which to a considerable extent was new. Used as a bond, this latex has underlain many new products. Its use has enabled rubber to be deposited electrochemically on metal surfaces. It took the place of older types of rubber cement. It has been used for impregnation and by a process of extrusion produces a fine rubber thread of uniform size which is at the basis of the greatly improved elastic industry, where various fibers are spun about this core and thus become elastic thread for many fabrics. Industries have sprung up as a result of the availability of such latex.

The effort to obtain new outlets for rubber products has already led to some expansion of production. Again in the effort to control noise, we find motor vehicles using more and more rubber parts to obtain silence. Experiments with rubber tires on streetcars and other railroad vehicles are cases in point. Extensive experiments have been made with rubber or rubber-coated blocks for highways and streets, particularly in the vicinity of hospitals, to lessen noise. Special products for the upholstery trade have been well received, particularly abroad, and vary from a latex rubber sponge of great elasticity, porosity, and light weight, to units composed of animal hair curled or uncurled coated with rubber latex and vulcanized into pads with thicknesses in accordance with their uses.

Another indication of the result of research undertaken to find new uses for rubber is the materials known as Pliofilm, Pliolite, Plioform, and Tornesit. These are chlorine compounds with the rubber hydrocarbons. The Pliofilm is a transparent membrane or film offered as wrapping material. It is naturally moisture-proof, is easy to seal at overlapping edges, perfectly transparent, and so thin that 25,000 square inches weigh but 1 pound. Pliolite and Tornesit are base materials for coatings and when dissolved in some of the cheaper hydrocarbons such as toluol or xylol have importance in the paint industry. Plioform is a molding material taking its place among the synthetic resins and plastics for special uses. As it contains no sulfur and does not absorb moisture, it has had some preference in the field of electrical insulation.

To be sure, the efforts to find new uses are somewhat in proportion to the supply and price of crude rubber, but they will continue, and something spectacularly useful may at any moment give rise to a new industry.

Synthetic Rubber

Concurrently research chemists have been successful in devising rubberlike materials synthesized to perform work which rubber cannot do. The outstanding examples in America are Neoprene and Thiokol, the former made from acetylene and chlorine, which, while selling for five or six times the cost of crude rubber, is nevertheless produced in very substantial quantity because of its special characteristics. For example, it is not soluble in petroleum and its products, is not so readily oxidized by ozone as is crude rubber, has a smaller particle size, which makes it preferable for some work of impregnation, etc. The other is Thiokol, which is the trade name for a polychloro-methylene polysulfide reaction product. The principal raw materials for this are natural gas, chlorine, and sulfur. There are a variety of Thiokols, in the production of which Edward Mack, Jr.'s theory of elasticity has been most valuable. The Thiokols, like Neoprene, are highly resistant to solvents, and as they increase in number and variety will offer increas-

ing competition to crude rubber. In 1935, Koroseal, a plastic resulting when highly polymerized vinyl halides are treated with plasticizers at elevated temperatures, was introduced. A later addition to the list is AXF., a rubberlike plastic prepared by reacting an ethylene dihalide in the presence of aluminum chloride with an aromatic hydrocarbon. Indeed, the threat of synthetic rubbers and rubberlike materials grows in various parts of the world and leads to the inquiry, Will they some day be another indigo causing acres and acres to go out of production of this national product, as did synthetic indigo not so many years ago?

It is difficult to predict the ultimate in the synthesis of rubberlike materials, but if carried to its logical conclusion in time we may see produced chemically in the area of an acre within a chemical plant, more material to give the service of crude rubber than would come from a great tropical plantation. Even now an acre of plant for Thiokol manufacture will produce in 2 hours, 200 tons of a synthetic rubberlike plastic, as compared to the 500 pounds of rubber which an acre of rubber trees will produce in 5 years.

Plastics

A development in the modern sense of the term within the last quarter century, plastics are still in their infancy, comparatively speaking. We have referred earlier to the pioneer, bakelite, which now finds itself in a field with hundreds of competitors, some of which have sprung up since the expiration of the bakelite patents, and others which are totally unrelated so far as raw materials and chemical process are concerned. Beginning with formaldehyde and phenol as raw materials for bakelite, experimenters have gone over and over the possibilities from casein derived from skim milk to glycerol, phthalic anhydride, cresols, urea, and many, many other raw materials. And cellulose acetate and other cellulosic products, acrylic resins, vinyl acetate, rubber derivatives, these are others in this highly competitive field, and yet it may be that the last word in plastics is far from having been spoken. The demand is for a comparatively colorless resin which nevertheless can be permanently colored, of high strength, and easily molded. From heavy steam-heated presses capable of developing high pressure, we have recently come to the injection type of molding, in which the thermoplastic resin is forced under pressure into the waiting mold somewhat as is practiced with metals in die casting. Articles of size and mass sometimes needed as an impeller in the washing machine, the case of an adding machine, or a weighing scale may perhaps not be made by this method, but smaller parts can be produced with a great saving of time and with satisfactory accuracy of dimension.

The several plastics have their unique characteristics indicating them for special applications. One cannot hazard a guess with safety as to the possibility of their replacement by newer types, but it seems certain that new types will appear either in the plants of those now in the business or perhaps as a product of wholly new undertakings. Plastics began their career as competitors of hard rubber, shellac, and various gums. They now compete with light metals and wood for structural purposes; they compete with adhesives for the manufacture of veneers and laminated wood; they are found as binders in abrasive wheels; they afford waterproofing qualities for surgeon's plaster and raincoats. They enter into coated fabrics and have made a major contribution to the serviceability of lacquers and coatings. Apartments have been constructed of them, they are used in decoration, they appear as insulating materials for units in the automobile and the radio. They require only to have higher resistance to abrasion to make them competitive with glass in airplane and motorcar windows and in lenses. Their development and use have reached the place where one contemplating a new product is most likely to enquire first of all, out of what plastic might it be molded? Highly competitive with metals and wood, the plastics nevertheless have made possible low-cost production of many molded articles with or without metal parts that would not have been otherwise attempted. The tribe is certain to increase.

Food

The extent to which changes in food habits have affected so basic an industry as agriculture is a topic of general discussion. Some of these changes have been due to technical improvements in the preparation and preservation of food as well as in its transportation. Others have had sound scientific reasons, particularly vitamins. Still others have doubtless been merely fads. In the preparation of food on an industrial scale, the contributions of science have been largely along mechanical lines, save for the control of sanitary factors and the provision of materials for equipment to prevent the acquisition of off flavors, colors, or odors. The glass-lined steel tanks, the noncorrodible alloys, the control of temperature, the factors in sterilization, and the very considerable contributions of the science of refrigeration indicate the lines along which most of the advance has been made. The preservation of foods prepared industrially has involved these factors of cleanliness and sanitation and in addition research on the container itself and again the proper use of refrigeration in transportation and storage.

Quick Freezing a Competitor of Canning

As the research goes forward on enzymes, chemical changes, the treatment of food to retain the potency of vitamins, it seems fair to assume that world competition for consuming markets will increase. Whether or not one may now enjoy a particular food out of season has become a financial rather than a technical problem. Note the success of quick freezing of certain foods. With a modern plate type of freezer in the field, the crop of strawberries may be followed from the far south as far north as they grow and the product prepared on the spot at the time the fruit is in the optimum condition. When used, these berries present the utmost in color, flavor, and fragrance that one can expect from the freshly picked fruit, and hence strawberry shortcake may be had any day in the year.

Vitamin Fortification

As the food accessory factors, such as the vitamins become better understood, the effort increases toward fortifying foods along this line. Thus there may now be had milk fortified in one or more ways with the important vitamin D. One is by the irradiation of the milk itself as in a thin film it flows by a light source so controlled as to expose it to that portion of the ultraviolet which causes an increase in vitamin D in the final product. Ergosterol, already present in milk, is the substance from which vitamin D is produced under the ultraviolet light conditions provided.

Another method is less direct and consists in irradiating the yeast which is then fed to the cow, and this leads directly to the fortification of the milk with vitamin D. This is known as metabolized vitamin-D milk which made its first appearance on the market in September 1931. Still another method employs a cod-liver oil concentrate.

Synthetic foods are still for the future, but even now vitamin C is available as a synthetic chemical and was taken on the latest Mount Everest expedition instead of bulky fresh fruits and vegetables.

Food Without Soil

In the last little while it has been demonstrated by Gerricke in California and others, that many foods, such as potatoes and tomatoes, can be grown with enormous yields without soil. Tanks of liquid plant food containing calcium nitrate, potassium nitrate, magnesium sulfate, potassium bisulfate, aluminum phosphate, titanium oxide, manganous chloride, boric acid, zinc sulfate, copper sulfate, nickel sulfate, and cobalt sulfate seem to be all that is required in addition to water and light. As used in the greenhouse, the tank also contains an electric heating cable to maintain a temperature at which the plants make the most rapid growth. One tank of exactly one-one hundredth acre of water surface produced 25.6 bushels of potatoes, and yields of other crops are equally impressive.

While the economics of this method of producing food have not been fully explored, the potentialities seem great, particularly when one remembers that cucumbers, tomatoes, and some other crops have long been subjects for hothouse treatment, that areas near large centers not suitable for various types of buildings might be so employed under glass, and that in many places even householders might produce much of their own food. It is yet to be proved whether it would pay to grow potatoes in tanks of nutrient solutions under glass in Pittsburgh in competition with those grown out of doors in Maine or Florida, but the implications of these large-scale experiments are not to be overlooked.

Agricultural Products for Industry

The story of the service of science in the utilization of agricultural byproducts is well known, with cotton-seed perhaps an outstanding example and with the utilization of packing-house byproducts a close second. Recently, however, the plight of agriculture has focused attention anew on work that has been in progress for some time. This is the effort to find non-food uses for agricultural crops, whether these be low-grade, surplus, or raised for the purpose. A new group, known as the Farm Chemurgic Council, seeks to be of service through effecting a new alliance between agriculture, industry, and science. It is too early to predict results, but there has been reason to believe that with the increased number of interested and capable investigators concentrating on this phase of our national problem, something will be achieved.

Chemistry has by no means overlooked agriculture, whether it be in aiding in the production and protection of the crop, in its preservation, or in its industrial use. There is much current interest in the use of the protein in soybean meal as the basis of a plastic, the use of the oil in the paint and varnish industry, the byproduct meal as a feedstuff or fertilizer; the growing of tung trees for the chinawood oil used in varnishes, the further refining of corn products, the use of additional species of woods for pulp making, and the establishment of economic facts with respect to the production of alcohol from different fermentable products.

Insecticides and Fungicides

This field while very difficult is one in which great advances may be expected. It is difficult because in killing insects the plant must not be unduly injured, and residues toxic to man, and too expensive or impossible to remove must not remain on fruit or vege-

tables. Cost is always a factor. The importance of continually combating insects and fungi cannot be overstated. The figure $3,500,000,000, is the measure of the annual loss in the United States caused by insects and plant diseases. These forms of life come to the conflict with man for his food supply far better armed, and unless successfully controlled might cause disaster at any time. Ornithologists tell us if birds were to disappear insects would soon overcome man, but our feathered allies are not enough.

Inorganic poisons such as certain compounds of lead, arsenic, mercury, copper, sulfur, calcium, and fluorine have been the ones principally used for orchards and field crops, although such organic materials as nicotine find wide use against aphids and similar soft-bodied insects. Unfortunately, many of the insecticides leave a residue toxic to man and this has become a serious problem. Methods of removing the residue have been developed, and other types of materials like manganese and calcium which are not so objectionable as arsenic and lead, have been employed in some cases, but the fruit grower in particular finds himself between the horns of a dilemma for on the one hand he is given strict tolerances for spray residue, and on the other if he uses no insecticides he will have no marketable crop.

Chemistry, aiding entomology, has taken up the gauntlet and enough has been done to indicate at least the trends which are likely to be followed. Organic materials are now offered which are useful in special cases, and indeed promising. Rotenone, derived from Cube and derris roots is very effective, but unfortunately rapidly loses its toxic properties under the influence of sunlight and air. The thiocyanates have given considerable promise and are now being widely used against certain insects, but they are not effective in all cases.

The perfect insecticide is yet to be found, but with the number of skilled men now engaged on the problem there is reason to hope that a noncumulative organic compound will be developed, which will protect our food supply and either be easily removed from the foodstuff when harvested or be nontoxic to warm-blooded animals.

Sulfur, so effective in control of fungi has been produced in a form approaching a colloid to aid in dusting, and studies are being intensively pursued to establish the reasons for its effectiveness as well as to investigate the toxic properties of other elements and compounds.

New discoveries may at any time entirely change the complexion of the insecticide and fungicide industry, and even when such a change comes it is likely to be succeeded by others, because some of the pests have an uncanny habit of becoming immune to a given poisonous substance. This is well illustrated by types of scale on citrus trees in Southern California which seem to have acquired an immunity to hydrocyanic acid gas, one of the most deadly chemical poisons, which until recently was very effective in the control of scale without damage to the trees.

It must be remembered that in this field of work the researcher meets many limitations. He tries to find a material toxic to the enemy but nontoxic to warm-blooded animals. It must not burn the plant, he would like it to adhere for a considerable length of time, its cost must not be too high, and so it goes through a number of factors in an equation which becomes increasingly complex and difficult of solution.

Solvents

Reference has been made earlier to the fact that one of the most active fields of chemical industry during the last decade has been in synthesizing a variety of new solvents, some of which until this took place being principally laboratory or museum curiosities. Many of these solvents have resulted from special investigations in the field of fermentation, but most of them have come from the application of high temperature-high pressure technique combined with advances in the field of catalysis. This combination of processes as they might be called, has been a major byproduct from the research on the fixation of atmospheric nitrogen, and affords an excellent example of how a trend may develop with rapidity when new tools become practical.

Much that has been done would have been regarded as impossible, and was indeed impossible under the conditions which formerly existed, but new conditions, principally with respect to pressures and temperatures have been created and these pressures and temperatures have been commercially practical because of still other research on materials. Undoubtedly if there were available materials that would withstand still higher pressures and still higher temperatures, other things might be attempted and accomplished. Just what, it is difficult to prophesy.

Now the trend in solvents will depend upon the new uses from them that may be found, and since most of them find extensive employment in the paint, varnish, and lacquer industry, the trends there will determine what solvents will be used or what must be synthesized to meet a new demand. There was a time when other factors would have demanded consideration, among them odors, but the criterion today is improved finish at lowered cost, and in attaining this odors are no longer given much consideration. What, with improved methods of ventilation, the use of partial vacuum to quickly draw away vapors that give rise to objectionable odors, and the spraying of materials as against brushing, which keeps the operator

in closer proximity to the solutions, odors, and changes in odors are of lessening consequence.

It must be remembered, too, that the solvents comprise little or none of the final composition of the coating material. They either evaporate rapidly in the quick-drying lacquers or are driven off by the baking ovens where enamels and baking type finishes generally are concerned. It is evident, therefore, since different types of solvents are used in these varieties of finishes, that the trend or style in the finish itself is the largest determining factor in what will be developed in solvents. Of course, if research shows that some organic chemical compound not in use will have better solvent properties, may impart the advantages of low viscosity or boils more nearly at a point desired for the finish in question, no doubt a new solvent would appear.

An example of the case in point is the rapidity with which the vinyl resins have been adopted for protective coatings in tin cans. Methyl ethyl ketone has become important as a solvent because it is reasonable in price and is an excellent solvent for this type of resin. Its production will be somewhat controlled by the success which the vinyl resins may have in holding the new market and serving related uses. Methyl ethyl ketone, however, has another important application, for example with nitrocellulose solutions, but here once more competition with ethyl acetate and isopropyl acetate exists. The introduction of the cellulose nitrate type of lacquer in which butyl alcohol was so important, and for which solvent previous to that time there was no extensive market, served to arouse interest in new materials for coating purposes. The advances since then have not been confined to solvents and vehicles, for improvements have been made in pigments, lakes, and in the physical aspects, involving particle size and a number of behaviors which when controlled serve to give greater durability, greater economy, and better protection.

Paints, Varnishes, and Lacquers

Titanium oxide has made rapid headway because of its intense whiteness and its resistance to those compounds in air and moisture which frequently cause discoloration in the case of other inorganic pigments.

The developments of the moment which indicate new trends which may have social implications have to do with tung oil, commonly called chinawood oil, and the utilization of soybean oil in various types of paints and varnishes. Both materials are from the Orient and the progress that has been made in growing tung trees in the South is a tribute to those who without much specific knowledge have begun with nursery studies and have continued to such complex questions as growth and fertilization to cause the maximum number of flower buds to be born along with the leaf buds. This means ultimate control which will cause the tree to yield the utmost in oil-bearing nuts, without detriment to its growth and metabolism.

The growth of soybeans in this country is not new, but the crop is receiving special attention in the hope that it will offer further diversity in agriculture with nonfood uses as the outlet for production. There are certain limitations in the use of the oil for coatings and it remains to be seen whether the disposal of the soybean meal will offer difficulties, especially in competition with press cake from flaxseed and from cottonseed.

Reference has been made previously to the rapidity with which synthetic resins of the glyptal type are making their way into lacquers. The raw materials for these resins are phthalic anhydride which is made from naphthalene which is derived from coal tar, and glycerine, a byproduct in the production of soap. The resulting film is extremely pleasing and durable, and such lacquers are widely used on refrigerators, automobiles, steamships, etc.

Some Glass Products

In industries so ancient as ceramics, with which glass is included, new developments are likely to come slowly. However, marked improvements have been made in the characteristics of these materials through a control of their chemical composition. Many of the spectacular products of today, like the 200-inch telescope disc, are direct results of such research. The borosilicate type of glass, varied to meet a special set of specifications, is a comparatively recent product and grows out of the attempt to produce a globe suitable to enclose a flaming arc of the type once urged for street illumination. The effort was to make a globe to enclose the arc which would withstand its heat and at the same time not be shattered in storms of snow or rain. But by the time the globe was perfected the flaming arc had been outmoded and the developing company had a considerable investment in a glass for which there was no use. The type of ovenware which has become so well known was the first outlet. Then followed scientific glassware, and since then there has been developed tubing and other forms suitable for factory use in competition with some metals. More lately glass that can be used directly over the flame or on the stove top has been introduced.

The great telescope disks so out of the question a generation ago can now be made an article of regular production if there are demands. Glass bricks for various buildings offer advantages in insulation and lighting and are now commercial. Any modern

building will clearly demonstrate the trend to introduce more and more glass as a structural and ornamental material, notwithstanding the trend toward having some types windowless.

Reaching over into the field of organic chemistry for the intermediate layer, safety glass has become almost a separate industry and offers an outlet where there is keen competition among such plastics as cellulose nitrate, cellulose acetate, vinyl acetate, and the acrylic resins, as materials to hold the sheets of glass together. The trends here are toward the development of still better plastics, easier to apply, less expensive, certain to make available acceptable visibility, and retain their plasticity at low temperatures, at the same time affording self-sealing edges when the safety glass is cut to dimensions. No automobile should be made with any glass other than the best of safety glass.

Scientific work which underlies improvements in modern glass may be relied upon to develop still other types to meet requirements. This may serve to open up new fields of glass utilization where competition is certain to be met, as in the field of insulation, and where new markets acquired will be useful in offsetting what glass may lose to paper containers and to tin cans in markets which it has dominated so long.

The lowered cost in glass articles is due in large part to mechanical improvements, as in blowing machines which manufacture an incredibly large number of electric-lamp bulbs, drinking glasses, glass tubes or bottles, in 24 hours. But these mechanical devices in turn depend upon physical characteristics in the modern glass which are attained only by a careful control of the chemical composition. Trends here may be toward greater output per unit with still lower cost of product, though at the moment it is difficult to see why still greater speeds should be necessary. Blowing machines have rid the industry of that type of work which was almost drudgery and in some cases somewhat detrimental to the health of the workers.

Ceramic Wares

Reference has already been made to the use of vacuumized or deaired clay in ceramic industrial ware, but trends here may lead to further competition of ceramics with other structural materials for equipment though the advent of various clad metals offers strong competition. The enameling of metals which comes under the classification of ceramics is one of steady progress, guided by demand for greater range of color and closely related to progress in the fabrication of metals as a choice for utensils. Formerly made of cast metal, stamped and welded bathtubs ready for the coat of enamel are now items of commerce which have presented a new problem in enameling with ceramic materials.

The trends in the manufacture of terra cotta, brick, tile, and the like have to do principally with ways to utilize new sources of raw materials, finding how to make use of more of our domestic clays, colors, and architectural effects, but there are introduced no factors which would lead to much immediate expansion of industry, effect established units, or give rise to new social implications.

Cement

This important unit in the chemical industry has profited extensively from mechanical improvements and inventions and has not lacked for improvement at the hands of chemical research. Some advances of note have been made in improving early strength, in devising means for quick-setting and in determining the relation of certain compositions to ultimate strength in service. Yet on the whole, with advances in other fields of technology there is a considerable opportunity for research. There is some resistance to change, due in part to the feeling of some that it is best to let well enough alone. This is evidenced by developments in the last year or two looking to the use of quantities not exceeding a percent or two of organic dispersing agents, believed by at least an important section of the industry to be potent in greatly improving the physical characteristics of the cement and concrete made with it. Heretofore fine grinding of the cement clinker has been the chief reliance for the same general type of improvement.

The fact that some addition agents have given poor results serves to impede new progress, but as chemical research becomes more and more applied in this field, it is to be expected that improvements will be attained such that smaller quantities of cement can be used for the same service. This is particularly true in the case of reinforced concrete and in structures where the concrete coating is used for the protection of the metal structure quite as much as for added strength. Earlier setting with high strength and permanence, and cements better fitted for special uses are objectives toward which trends are leading the industry.

Closely related to cement are the synthetic building stones, of which "Rostone" is a conspicuous example. This is a new development, employing commonly occurring aluminosilicates such as shales and slates which react with alkaline earth bases like lime in the presence of water at slightly elevated temperatures, forming this synthetic stone. Fillers include those to produce colors and are added to the reacting materials. The process is one that can be employed, if desirable, on a small scale, and with the raw materials so universally distributed gives promise of becoming a new industry. The variations possible in form, color, and texture, give attractive architectural material.

Detergents

While a certain amount of improvement has occurred from time to time in the field of detergents, it has remained for real progress to be made in the present decade, largely because of the availability through synthesis of a number of organic chemical compounds previously economically unavailable.

The earliest of these made their appearance in detergents about 1932, and were given the trade name "Gardinols." These compounds are of the type of sulphonated higher alcohols such as lauryl prepared by the hydrogenation of coconut oil. A number of other materials have since been devised for similar service, notably sodium metasilicate, sodium metaphosphate, and a series of organic compounds. These materials are important in decreasing surface tension and in either preventing the precipitation of calcium and magnesium salts of the fatty acids present in soap, or in rendering these soluble once they are formed. This simply means that these new detergents used either as water softeners or with soap itself, make possible certain cleansing operations in any kind of water. Consequently their use is spreading rapidly in the textile industry, in laundries and for domestic use.

Present trends in this field, therefore, have to do with discovering or devising still other compounds that may be more efficient, more economically available, or suited for some special type of large scale use. Thus far, they have not offered serious competition with soap and the like, but they do make possible its more efficient use with greatly increased satisfaction on the part of the user.

New Applications of Dispersing Agents

The success of dispersing agents in this field has led to a number of interesting, important developments as byproducts. Thus we find carbon black, ordinarily stirred into a liquid medium with greatest difficulty because of the tendency of the particles to adhere or "ball", has now been so prepared that the particles actually repel each other and become evenly and quickly dispersed in liquids or other media. Modification makes carbon black available for the treatment of cement, imparting a gray or even black color to surfaces to reduce glare.

Other dispersing agents are incorporated with dyestuffs to facilitate accurate printing of textiles. They find a use, too, in dentrifrices and in a number of other applications where lessened surface tension is advantageous. To mention a final example, with their aid expensive flammable solvents are now replaced by water in the preparation of some types of lacquers, particularly those to be applied to porous surfaces. They have also proven of great value as flotation agents.

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Fermentation Industries

These industries are on the borderland between chemistry and microbiology, but their revival following the repeal of the eighteenth amendment comes at a time when chemistry is in a position to contribute materially to progress and perhaps influence trends.

Heretofore, notwithstanding the excellent work that has been done in developing special ferments and many other contributions of that type, fermentation itself was not under the same control as we find today. The improvement in equipment through the use of glass-lined tanks and the like, the newer alloys, etc., contributes much, while with carefully sterilized mash and a better control of fermentation, the natural result is a more uniform product which materially lessens time required for the adjustment of the product. It is held by many specialists that the period commonly known as aging has been after all a period of adjustment within the final product.

The fermentation of cellulosic materials is of more recent origin. A semicommercial plant is operating in the United States on a process already employed abroad. Such important products as acetic acid, propionic acid, butyric acid, and some of the alcohols are already products of such fermentation. The possibility of using waste plant tissues such as corncobs, sawdust, cornstalks, and other wastes through fermentation is interesting, though yields thus far are too low to make this a commercially attractive undertaking. But there is always the prospect of determining those conditions which will give better yields and lead to the development of entirely new industries. We have already cited as an example cellulose propionate as a desirable compound which will be made when the price of propionic acid can be lowered to say 5 or 6 cents a pound.

While fermentation is ordinarily thought of in connection with the beverage industry, it offers many possibilities in the manufacture of chemicals, and citric acid is now produced in a large volume to compete with that heretofore derived solely as a byproduct of the citrus fruit industry. Investigation continues in many quarters because there are obvious advantages in the employment of various organisms, which for their compensation require only suitable food, protection from other forms, and conditions especially suited for their rapid growth.

A possible use of city refuse, such as garbage and sewage, to supply fuel gas by fermentation is having serious consideration. It has been the subject of considerable research and some commercial-scale development, with plants now being evolved for large installations. Should such methods play a dominant part in supplying gas to a community, there would doubtless

be an effect on other sources of fuel such as gas manufactured from coal. Much has also appeared in the literature to indicate the possibility of producing gas for fuel in rural communities by the fermentation of waste cellulose products.

Synthetic Organic Chemistry

The term "synthetic organic chemistry" includes so vast a field that to discuss it adequately is beyond the scope of this report, yet merely to mention it would be an injustice. Organic chemistry is dominated by the compounds of carbon. It is from research in this field that the great coal-tar chemical industry has come. It is here that the cellulose developments belong. Here, too, are found diphenyl and other compounds just coming into use in power plants to do the work water does in boilers. Solvents from many sources are in this category; pharmaceuticals, and medicinals, the chemistry of growing and living things. While much has been done in the field of inorganic chemistry to find new uses and new materials for established uses, it is in the field of organic chemistry that synthesis holds sway and has laid the foundation for a long list of new enterprises.

There are hundreds of thousands of organic compounds possible. Something is known of perhaps a quarter of a million organic compounds, but from the point of view of the public, only a fraction of these are at present important. It seems definite, however, that the future will see a rapid expansion of such a list.

Looking backward we can note the social implications growing out of the synthesis of such dyestuffs as alizarin and indigo, but what can be said of the possibilities of synthesizing practically to order new compounds designated by the medical profession as desirable in combating certain diseases? What has been done in alleviating pain and prolonging life through the aid which synthetic organic chemistry gives medicine justifies the prediction that before the physician is able to give the chemist a blueprint of the molecule he needs, the chemist will have progressed to the point where that molecule can be synthesized.

Synthesis not only pertains to new compounds unknown in nature but to the preparation under controlled conditions of naturally occurring compounds of constant characteristics. In no field has the leveling influence of research been more greatly felt than in the field of synthetic medicinals and pharmaceuticals, where now anyone for a few pennies can purchase for his use materials which once would have brought a king's ransom. Also in the "5 and 10" one may buy fabrics of better dye than the Tyrian purple once reserved for the ruling class and the Church. This sort of research goes forward with every promise of revolutionary discoveries in the future.

It is probably fair to say that practically all of the developments in synthetic coal-tar dyestuffs have been in the field of organic hydrocarbons, particularly concerned with the benzene ring. The advent of new textile materials like cellulose acetate, one of the chemical fibers, has directed interest toward the aliphatic hydrocarbons of the straight-chain type and while a little more than a decade ago acetate dyes were considered oddities, today they are generally available and show superiority in dispersion, brightness, and general dyeing properties. Acetate yarns today are dyed at reasonable cost in any of the fashionable shades.

There are those who believe that while research with dyestuffs based on the benzene ring will not be abated, we may look for many new and important dyestuffs based on the other types of hydrocarbons. Concurrent commercial production of the new and unusual solvents, many of which have been derived from petroleum gases, the glycols and higher alcohols, has been a most helpful factor in the use of both old and new dyestuffs.

In synthetic organic chemistry we find research in progress intent upon discovering new things which may be useful, and when once found devising commercial uses for the products. Others are busy correcting defects which practice has shown to exist in items of commerce. Others seek new combinations of elements which are very much needed to accomplish some definite objective. This was done, for example, in the case of some of the synthetic rubberlike materials discussed elsewhere, with the belief that when perfected they would offer advantages not possessed by the natural product.

From a field so vast, touching the public at so many vital points, it must be that an ever-increasing number of useful products will come. We do not know what they will be nor just how they will be used, but that they will have profound effects may be taken for certain. They will disturb industry by superseding old products and offering new employment. They will affect social problems by helping decrease, if they do not eliminate, certain ailments only to leave the race subject to still others. Vitamins, hormones, and the glandular products have been or will be synthesized and in time their use may have a profound influence on the human race. Improved colors and perfumes will have their effect upon esthetic senses. New products will offer new structural materials, just as the plastics and chemical fibers have done. They will aid in combating rust and corrosion, expand the opportunities for culture, and contribute to safety and "better living through chemistry."

Chemical Warfare

The preference of the chemist to perform work that is constructive is likely to be forgotten in any popular

discussion of chemical warfare. Many news writers have delighted in drawing upon their imaginations in the effort to present the chemist in his hide-out laboratory working for the destruction of his fellows. If the scientist could perform as the occasional and happily infrequent news writer would have him, then indeed he would be a magician.

The facts about chemical warfare are reasonably simple. As it was developed in the last World War, the use of chemicals constituted a new weapon, although it should not be forgotten that chemical reactions have always been involved in warfare since the invention of gunpowder. The investigations conducted by medical men under the Veterans' Bureau tend to show that, however abhorrent psychologically and actually, chemical warfare nevertheless is more humane than that in which combatants are killed or wounded by shrapnel, bayonet, and the older forms of weapons. At least the intelligent can protect themselves against an attack with chemical reagents, and nontoxic smokes can be used to protect life quite as much as the toxic variety can be used to produce casualties.

Since the World War the developments in the United States in chemical warfare have been principally along lines of defense. Great improvements in gas masks have been made, rendering their use far less fatiguing and objectionable than were the older models. The difficult problem of protective clothing has had special attention and in some quarters that of mass protection. Those in chemical warfare do not foresee the destruction of cities by gas from the air, and the experienced military man still prefers the high-explosive bomb and shell for such destruction. They destroy physical equipment like power-houses and factories, bridges and railway terminals, whereas an informed city, especially in these days of air-conditioned rooms and buildings, could rid itself of chemicals, which are in fact liquids or solids, in most cases without great difficulty.

But chemicals designed for either offense or defense are effective, are cheap as compared with ordinary ordnance, and it seems likely that in event of a war their use would be taken up at about the point where it was left off at the close of world-wide hostilities. What might be developed from that point on is difficult to say, but it seems certain that any nation hard pressed can be depended upon to defend itself with the best and most effective weapons it can secure, regardless of treaties. Even when not hard pressed, such aids as chemicals give are likely to be employed, as witness the recent Italo-Ethiopian war.

The chemist, then, wishing to be constructive, points to the futility of endeavoring to outlaw by convention an effective weapon, and pleads instead for the outlawing of war itself and for devising some sane and rational way of settling national disputes without recourse to the hideous procedure of killing one's fellow beings.

New Competition and Natural Monopoly

Characteristic of the chemical industry is the new competition which it has introduced. The new competition is that which exists between products devised to perform the same services. While their availability gives the user a great latitude of choice and in many cases a better opportunity to express his individual tastes and satisfy his personal judgment, it nevertheless means that to compete in the new competition an industry finds it necessary to lean heavily and constantly on the support science can give.

There are many examples. The choice one has today in buying refrigeration is due among other things to advances in the refrigerants themselves and to the perfection of mechanical and electrical devices. Time was when the only choice was between dealers all of whom sold only ice and natural ice at that. There is an enormous range of choice in the synthetic resins and in coating materials and so on through the list. The new competition is becoming intensified rather than otherwise.

It must also be remembered that chemistry and its sister sciences together have gone far toward breaking national natural monopolies. The result has shown in the nitrate situation, in independence with respect to methyl or wood alcohol, now synthesized more cheaply than it can be produced by the distillation of hardwood. We no longer depend upon Japan for camphor and silk, nor upon Mexico for vanilla. Potash is produced in our new country either by the application of physical chemistry to the complex salts of Searles Lake or from mines discovered through systematic search in the Southwest. We go to the sea for our bromine and to California rather than to Chile for our iodine. Germany hydrogenates brown coal for motor fuel, and thereby gains a degree of independence.

Perhaps the most outstanding trend in the chemical industry since the war has been that for all industrial nations of the first class and many others to strive toward national independence, particularly in the production of strategic chemical materials. In addition, tariff barriers, exchange fluctuations, and political situations have emphasized in some quarters, notably Germany and Italy, the desire for synthesis on a grand scale.

During the present century chemistry and the chemical industry have been most potent in creating a fourth kingdom and a fifth estate. There has been added to the animal, vegetable, and mineral kingdoms, the new one of synthesis; while to the lords spiritual, the lords temporal, the commons, and the press, there must now

be added the fifth estate of the scientists, who more than all the others, guide the destinies of modern civilization.

This is not likely to happen unless the plans for the future include adequate provision for support in continuity of fundamental or basic research undertaken primarily to advance the frontiers of knowledge rather than for immediate monetary gain. The progress so notable in the present century is based primarily on accumulation throughout two centuries of knowledge to which unnumbered scientists have contributed. While there is a more widespread interest among Government agencies, academic institutions, and industrial concerns in research in pure science than at any other time, this must not be allowed to decline and should be increased rather than diminished. What has been done and what has been established to be fact, however impressive and extensive, indicates more than anything else the real paucity of our information, the need for further and more difficult investigation, and emphasizes the possibilities in terms of various social implications that could result if we but knew more of the ways of matter.

Social Implications

It is most difficult to forecast what the social implications may be as we go forward with chemical research and the applications of its results. Sir James Irvine once said that by the modesty of their predictions do scientists justify faith in their work. Notwithstanding carefully planned investigation, unexpected by-products of such activity may be the very ones that will have the most far-reaching effect. When Maxwell, Hertz, and others began their investigation of short wavelengths, no one could have imagined the variety of almost vital applications to which X-rays are now put. There are many such examples which make the scientist hesitate to put on the robes of the prophet.

There are certain things that science hopes to do, limited by the natural laws as they are understood, but suppose someone finds a way to ignore a natural law, then what may happen? Much has been said and written about releasing atomic energy and utilizing the vast forces that it represents. While we see no immediate possibility of doing this economically, who shall say that it will not be achieved, and once achieved, how shall we estimate the social implications resulting from the use of such energy?

Even though something is known of work in progress, one cannot say when it will reach a stage that will produce social implications. Thus for some years development was conducted on Kodachrome, the present popular method for amateur motion pictures in color. The commercial product made its appearance in the spring of 1935, but so unpromising had it appeared to be that less than 2 years previously the project was on the eve of being dropped. Now more than 75 percent of the popular 16-millimeter width is supplied in Kodachrome, and the percentage is growing. It is the unexpected turn, when some little detail has been perfected after long search, that brings such things to pass, just as occasionally a promising development must be dropped when some unexpected defect develops. These are what make prophecy difficult.

The Science News Letter recently discusses in a single issue tanks of liquid plant food that yield potatoes at the rate of over 75 tons to the acre, a method for determining one part in one hundred thousand of certain elements in the blood, the importance of fresh green-grass juice in promoting growth, the announcement of the first compound of an enzyme that has been discovered, the proposal to manufacture beer from prunes, the discovery that neutron bombardment is fatal to germ cells, a new wrapper for soap comprised of a thin membrane of rubber latex, and the relation of developments at Tennessee Valley Authority to providing phosphates for the soil.

What has been done thus far through applied science in lifting burdens from the backs of men seems in some instances to have gone to the point where there were too few burdens for men to bear. That is a challenge to the utilization of the fruits of science and should not suggest curtailment of its work. Famines have become questions of transportation, purchasing power, and the weather, rather than technology or plant food. Facilities for housing and clothing have been enormously extended, and while many human ills remain to be understood and mitigated, the record of science in protecting health and prolonging the period of productive life is commendable.

Doubtless the inventions through science in future will continue to change industry to the point of causing periods of difficult adjustment for employees, unless planning provides some way to lessen this difficulty. Old industries and certainly old products will disappear in favor of new ones. A wise use of what is provided will create greater leisure and more desirable products to be possessed at low prices. The problem would seem to be how to use what can be produced in a way to be equitable, while at the same time planning to employ suitably for cultural and other activities the increasing leisure which may be prophesied for the race.

VII. THE ELECTRICAL GOODS INDUSTRIES

By Andrew W. Cruse [1]

Introduction

Probably no other line of human endeavor has produced as many technological developments, both for its own use and for the use of others, as have been produced by the electrical goods industry. The reason is simple. It is because this industry has at its command a servant far more accomplished than Aladdin's Genii, but equally mysterious. While many of the accomplishments of electricity appear miraculous, it is because of our own human limitations that its work has not been utilized to an even greater extent. We do not know what to ask that electricity do next.

Our research laboratories, with whom we have entrusted the responsibility for developing the answer to the above query, have a never-ending task. In many cases one group of research engineers develop a function which may appear utterly useless to the line of endeavor which they are primarily interested in assisting, but which may at the same time be the very key for another group similarly employed but serving an entirely different line of endeavor. It is not within the power of any one human being to fully appreciate the implications to all fields of each small development in our laboratories, and consequently one of our most difficult problems is the dissemination of information developed by research in order that we may reap the fullest benefits from the efforts of all groups. Naturally, in many cases the possible application of a development is obvious, but it is with the small, fragmentary discoveries which seem so insignificant and unimportant that we must concern ourselves, discoveries which seem so insignificant and unimportant to the one who views them first that he often casts them aside.

Thus, in the electrical goods industries research has naturally been regarded as essential because it is recognized that so little is known of the basic actuating force of these industries. So many new beneficial developments remain to be discovered in this field that the necessity for an increased efficient effort cannot be overemphasized. The twin results of this effort are inevitably those items which make for a more abundant life and those items which supplement our efforts to perform our daily work.

As a consequence, our concept of just what comprises our daily work is in a constant state of revision. No longer do we regard such tasks as the hunting and killing of our own meat, the chopping of wood, the drawing of water from wells or springs, the weaving of cloth, the preparation of suitable means for providing illumination during the hours of darkness, as a part of the daily work of civilized mankind generally. Yet it was a few short years ago that these tasks were considered as much a part of our daily routine as we now regard the preparation of our food for consumption, the maintenance of cleanliness of our homes and persons, the dictation and signing of correspondence, or the necessary effort to convey ourselves to the nearest terminus of the transit system which will carry us about in the performance of our present concept of other daily work. This gradual, subtle change in our daily work has been taking place so quietly that we do not realize that it has been happening. That we must perform our daily work in order to provide a means of livelihood may be a basic principle; but it would appear to be an equally basic principle that we may never be in a position to judge just what that daily work will consist of 25 or 50 years beyond the point from which the observation is made.

In the paper which follows, no attempt can be made even to catalog the vast number of electrical devices now in use. With hundreds of thousands of separate and distinct types of articles now being manufactured by the electrical goods industries, it has been possible to discuss but a small percentage of them in this paper. However, the author has made every effort to select those items which appear to have the greatest social significance and which have the broadest applications in our daily lives. Such items as electrical devices utilized in industry have been omitted from consideration inasmuch as they are dealt with in other chapters. The problem of presenting such a vast array of material and the irregularity of the material itself have made a practical classification difficult. Hence, while part I treats of particular inventions which are utilized in many situations, part II deals with inventions related more specifically to certain activities or functions.

[1] Formerly Chief Electrical Division, Bureau of Foreign and Domestic Commerce, Department of Commerce, but now Assistant Chief Engineer, Federal Communications Commission.

PART I

Climate

Air Conditioning.—Air conditioning has undoubtedly grasped the public fancy and it is now in great demand. That engineers are doing everything possible to supply this popular demand is indicated by a recent statement by a patent attorney to the effect that applications for patents on air-conditioning devices have been coming into the United States Patent Office at the rate of 300 a day.

Let us first consider just what is meant by air conditioning. Air conditioning in its fullest sense includes cooling, heating, circulating, cleaning, dehumidifying, and humidifying the air. Systems are now on the market which accomplish all of these functions, while others are designed to accomplish only one or a part of them. A few manufacturers will add to their equipment a device for absorbing all noise from the air entering a room. Strangely enough people seem to have become "noise conscious" in recent years and are demanding a greater degree of quietness from much of the generally used equipment. The almost silent electric fan has found a ready market for this reason. Much greater development along the line of quietly operating devices to replace noisy equipment can be anticipated.

Most of the electric-powered air-conditioning equipment now on the market is constructed to cool, dehumidify, and circulate room air and is adaptable to almost every type of structure.

Air conditioning for comfort may be said to date back to the days when the primitive man first used fire or to the days when slaves fanned their masters; but even today we have been unsuccessful in our attempts to duplicate artificially the perfect, invigorating air conditions which nature provides. Bearing in mind that air conditioning includes heating as well as cooling, it is interesting to note a quotation from a paper by Prof. C. P. Yaglou of the Harvard School of Public Health:

> It is now beginning to be recognized that our present heating methods are crude and much less healthful than nature's method. There seems to be a great difference between the sensations of warmth, comfort, and well-being, produced by solar radiation falling upon the human body on a pleasant cool day, and those which arise in rooms heated by the usual convection methods. The assertion is often made that the common cold and other more serious respiratory diseases begin with the heating season, and there are good reasons to suspect that the effect may be due, at least in part, to the source and nature of radiation employed in modern heating systems.

It would appear then that in order to duplicate natural conditions from a physiological viewpoint the health-giving rays of the sun found in its infra-red and ultra-violet spectra as well as those in the visible spectrum will have to be provided as well as the types of air-conditioning described above.

As early as 1857 attempts were made to air-condition railway cars and at the present time this equipment has been so perfected that it is almost regarded as standard equipment in all types of accommodations.

Experimental work is now being carried on in the field of air-conditioning of passenger airplanes through the use of solidified carbon dioxide ("dry ice") and the time is not far away when the interiors of our automobiles will be supplied with air-conditioning apparatus. Several types of air-conditioned bed canopies are already available and "room coolers" for our homes and offices have been on the market for several years.

Heating.—With the reduction of the cost of electricity more and more use is being made of it for heating foods, homes, water heaters, and incubators, and hotbeds.

Electrically heated hotbeds originated in Sweden but their use has expanded rapidly, one hotbed containing over 3,000 square feet being located 100 miles north of the Arctic Circle. At the present time about 20 percent of the hotbed area in Norway has been electrified and thousands of truck farmers from Vermont to Oregon have found that electric hotbeds to germinate and develop healthy plants may be a large factor in increasing income. Other applications of the heat produced by electricity range from sterilizing surgical instruments to the removal of snow from sidewalks.

Refrigeration.—A very typical example of technological development in the electrical-goods industry is the progress made in the field of refrigeration. During the 10-year period 1926 to 1935 it is estimated that 8,255,000 domestic electric refrigerators were sold and, making a reasonable allowance for replacement and multiple sales, it is estimated that while on January 1, 1936, 34.2 percent (7,250,000) of our wired homes were using this convenient method of refrigeration, 65.8 percent (13,954,354) of our wired homes were without it.

The natural assumption in a consideration of the development of the mechanical (both gas and electric) refrigeration is that it has progressed at the expense of the ice industry. But is this so? The following figures from the United States Bureau of the Census, which show the production of ice in the United States by the ice industry in thousands of tons (2,000 pounds) would rather indicate that this is not so, certainly not to any disastrous extent:

1925	38,813	1931	42,355
1927	39,057	1933	32,888
1929	44,477	1935	[1] 34,324

[1] Preliminary 1935 estimate by National Association of Ice Industries.

The commercial uses for ice are increasing, and the ice-manufacturing industry is especially interested in the development of equipment which will utilize ice to cool homes and commercial buildings.

The manufacture of ice boxes, on the other hand, has dropped as precipitately as the production of electric refrigerators has risen. Sales of ice boxes in 1930 were less than half a million, according to reports, as compared with nearly 1,300,000 in 1924 and in 1926. Each succeeding year has shown further declines; but although unit sales of ice boxes have been declining, two or three makes of the "de luxe" variety have been enjoying good volume. It is the market for cheap ice boxes—which formerly comprised the vast bulk of production—which has contracted.

A comparison of the sales of electric refrigerators since the beginning of that industry in 1920 with the sales of ice boxes over the same period clearly demonstrates that even if the same number of man-hours were necessary to produce each, no technological unemployment could have resulted from the introduction of this development.

TABLE 18.—*Sales by years of refrigerators and ice boxes*[1]

Year	Electric household refrigerators sold	Ice boxes sold	Year	Electric household refrigerators sold	Ice boxes sold
1920	10,000	737,000	1928	560,000	980,000
1921	5,000	571,000	1929	840,000	1,053,000
1922	12,000	760,000	1930	850,000	419,000
1923	18,000	1,139,000	1931	965,000	282,000
1924	30,000	1,282,000	1932	840,000	213,000
1925	75,000	1,231,000	1933	1,080,000	244,000
1926	210,000	1,290,000	1934	1,390,000	276,000
1927	390,000	1,116,000			

[1] Refrigeration and air-conditioning market data, Business News Publishing Co., Detroit, Mich.

The introduction of electric refrigeration has unquestionably changed the buying habits of many people. Perishable foodstuffs can be kept for longer periods even in tropical climates, and larger quantities may consequently be purchased (usually at a saving) by small families. Apartment house owners have been quick to appreciate the fact that an installed electric refrigerator adds to the appeal (and in many cases the rent) of their units.

Electric refrigeration has greatly contributed to the ease with which various medicinal products and serums may be preserved; and has made the preservation of perishable foodstuffs possible, even in remote areas where commercial ice was never available. In addition to the domestic electric refrigerator, we also find developments in the commercial field. One of the largest and most profitable markets for commercial refrigeration is the dairy industry. Low-temperature show cases for the display of perishable foods will keep those foods almost indefinitely, and we are now seeing the engineers of the electrical-goods industry assisting in the solution of the problem of providing refrigerated trucks. This demand for satisfactory mechanically refrigerated trucks has arisen from dairies and ice-cream manufacturers, and from producers of quick-frozen foods.

Ultra-violet and Infra-red Rays.—Strange as it may seem, the part of the sun's rays which are most beneficial to our health are completely invisible. Our eyes are built to register only certain parts of the sun's rays, just as a radio is capable of receiving waves of only certain lengths. There can be no disagreement with the idea that sunlight is essential to our health, but how many people today realize that the rays which really contribute most to our health do not pass through ordinary window glass? Because these health-giving rays cannot be seen and because so much time is spent indoors, it is becoming more and more important to give attention to providing these rays artificially.

There are two distinct types of rays produced by sun-ray lamps. One is the ultra-violet ray and the other, the infra-red ray.

The ultra-violet ray contains very little heat and reacts on the blood stream of the body, increasing the supply of the valuable vitamin D, and producing the well-known effect of sunburn technically called "erythema." This ray is of great benefit in preventing and curing rickets and in building up sound bones and teeth, improving general health and building resistance to disease.

The other type of invisible ray produced is called the infra-red ray. This is a heat ray which penetrates beneath the surface of the skin and is helpful in relieving pain, relaxing spasm, and promoting circulation.

While artificial sunlight equipment has been used by physicians for a great many years in their treatment of disease, it is only within recent years that lamps which are safe and convenient for the home have been available. The first equipment perfected for home use was very similar to that used by physicians. These devices were large and rather cumbersome units which produced a very high percentage of the valuable invisible rays—such as would reach us from the sun if it were not for the clouds, dust, and smoke in the air, and for the ordinary window glass which filters out many of the beneficial rays.

The advance in the art of producing artificial sunlight has been so rapid during the past few years it is entirely possible that, within the next decade, the usual illumination in the home will include sufficient ultra-violet to afford most of the healthful benefits of sun-

light itself. Already these units are available so that midsummer sunlight may be had in any home and the benefits enjoyed while reading or bathing, or while the children are playing regardless of the season or the weather.

And so it can be seen that some of the technological developments in the electrical-goods industries are enabling man to control his climatic conditions indoors. The effects of this ability upon daily life will be further discussed in subsequent sections of this paper.

Vision

Lighting.—Thomas A. Edison produced the first commercially successful incandescent electric lamp in 1879. This was the beginning of the incandescent-lamp industry, but its growth depended primarily upon the development of economical sources of current. Edison realized that, and it was largely through his efforts that the first central station for the supplying of electric current was constructed in New York in 1882. The carbon-filament-lamp industry grew with the central station industry until nearly 50,000,000 carbon-filament lamps were sold in the United States during 1906. The rapid growth of the industry since that time is directly traceable to technological improvements and inventions which are making this source of illumination constantly more economical and efficient.

Year	Total large lamps sold [1]	Lumens per watt	Cost power per kilo-watt-hour
1906	57,000,000	3.4	$0.1120
1935	413,000,000	13.9	.0503

[1] Does not include miniature, automobile, or Christmas-tree lamps.

It seems altogether likely that such progress will continue rapidly, since we are still getting as light from the most efficient, big tungsten lamps only 15.5 percent of the current used, which means 2.2 percent at best from the coal burned. The cold light of the firefly is 96.5 percent light and only 3.5 percent heat; and we are beginning to understand and are experimentally copying his secret. Already great strides forward in the improvement of the efficiency of artificial illumination are being made in vapor lamps; for example—the present commercially available 400-watt high-intensity mercury vapor lamp produces 40 lumens per watt. Unfortunately, this mercury lamp gives an unpleasant bluish glow. Likewise, sodium vapor gives a yellowish glow, which chromatic properties make these lamps at present unacceptable for general use. It is entirely reasonable to assume that in the near future we may be able to closely duplicate the sunlight spectrum by a combination of those or other vapors in a single highly efficient lamp. However, some day the direct use of electricity for illumination may be as obsolete as the use of whale oil now is. This perhaps may be accomplished through the economical manufacture of synthetic luciferin which when oxidized by the air gives cold, firefly's light, almost 100 percent efficient, diffused, not glaring, and involving no fire risk, wiring, or electricity. There may be luminescent paints which may store up sunlight during the day to glow with various colors during the night.

Much research is being carried on in the field of illumination to determine accurately the lighting requirements for the best performance of various tasks. The results of this work will be manifested in the prolongation of better eyesight in future generations. Already it is not uncommon to find schools equipped with the ever alert photoelectric cell to switch on classroom lights when the illumination from outdoors falls below a predetermined point. The lightmeter, which provides a convenient method of reading the existing illumination in foot-candles has just recently been supplemented by the visibility meter, which provides an equally convenient means of determining the foot-candles recommended for the performance of a given task. The research in this field has really only begun, but indications are that we will eventually be able to discover means not only of conserving our very valuable eyesight but also will be permitted to perform our daily work, whatever it may consist of, more efficiently and comfortably and leave those tasks less tired and less nervous.

Great progress has been made in the field of outdoor lighting, flood lighting for the beautification of nature and man-made buildings and objects, lighting which makes possible outdoor sports events at night, the landing of aircraft in darkness, the reduction of crime through better street lighting, and advertising by electric signs using both incandescent lamps and luminous tubing containing neon and other gases. Much work remains to be done in the field of stimulating plant growth by the use of artificial lighting.

Highway Lighting.—One of the applications of outdoor lighting which offers the greatest possibilities is the lighting of our highways.

Modern automobile headlights are designed for use with lamps having two beams; one of which is a raised beam for use when driving on the open road, and the other is a depressed beam for use in approaching another car. When properly focused and adjusted and with lamps and reflectors in perfect condition, they provide adequate visibility on straight, level, nonspecular roads. However, statistics compiled by the Travelers Insurance Co., based on inspections of thousands of cars in various cities and States, reveal that

in 63 percent of the cases headlight adjustments or lamp replacements are required.

Even more important for the safety of driver and pedestrian alike, especially after dark, are the extent and nature of highway lighting. Increased speeds of driving have made even more imperative dependable visibility. Proof of the importance of adequate illumination in the prevention of night accidents is available in numerous reports covering most parts of the country.

The National Safety Council obtained the figures used in the following chart (see fig. 46) from the commissioners of motor vehicles in the States of New Jersey, Oregon, New York, North Carolina, and Pennsylvania. These States have almost one-quarter of the population, automobile registration, and gasoline consumption in the United States. (One curve shows the total number of fatalities for the summer months of May, June, and July. The other shows similar data for November, December, and January.)

It is observed that the two curves are approximately the same, except for the period 5 to 8 p. m. Why should there be such an abrupt rise in accidents after 5 p. m. in winter? Winter traffic is known to be less than that in summer. This accounts for the fact that during the daylight hours there are fewer winter accidents than in summer (although the effect of reduced traffic in winter is partially offset by that of slippery road surfaces). However, in the hours of 5 to 8 p. m., which are hours of daylight in summer and darkness in winter, the winter accidents are 58 percent higher than the summer accidents. The only possible reason for this increase is the lack of illumination in winter. In the hours of daylight in both summer and winter, the winter accidents average 76.4 percent of the summer accidents. Based on this percentage, the expected winter accidents during the period 5 to 8 p. m. are as shown by the broken line on the chart, and the shaded area represents the amount chargeable to lack of illumination. This shows that a reduction of 47 percent in night accidents resulting in fatalities should be possible if illumination equivalent (for purposes of seeing) to daylight conditions should be provided on the highways. Considering all the limitations of artificial lighting, it seems reasonable to believe that at least 35 percent of the night fatal accidents should be prevented by the provision of adequate highway lighting.

In 1933, R. E. Simpson studied the day and night fatality rate for 60 cities in comparison with the accident exposure. He considered the traffic unit (a measure of exposure) to consist of either one pedestrian crossing the street or one automobile traveling 1 mile. He found that the average day fatality rate per M. T. U. (million traffic units) on streets carrying over 1,500 automobiles per hour during the lighting period was 0.046. The ratio of night to day fatalities on these same streets according to the grade of street lighting was:

Grade of street lighting (lumens per foot):	*Ratio of night fatalities per M. T. U. to day fatalities per M. T. U.*
A, 80 or more	8 to 1
B, 40 to 80	12 to 1
C, 25 to 40	21 to 1
D, less than 25	47 to 1

While the extension of highway lighting may be justified on the basis of cold dollars-and-cents economics, based on anticipated reduction of night accidents, numerous other social effects may be expected. Some of these are the following:

(*a*) *Reduction in Highway Crime.*—It has been shown time and again that in cities the installation or improvement of street-lighting facilities invariably led to a reduction in street crime. Crooks work in the dark. Similar results may follow the lighting of the highways.

(*b*) *More Efficient Utilization of the Highways.*—Estimates show that about 80 percent of the traffic is in the daytime and 20 percent at night. This means that the tremendous investment in our highway system is being wasted during the hours of darkness. People try to avoid night driving because they realize that

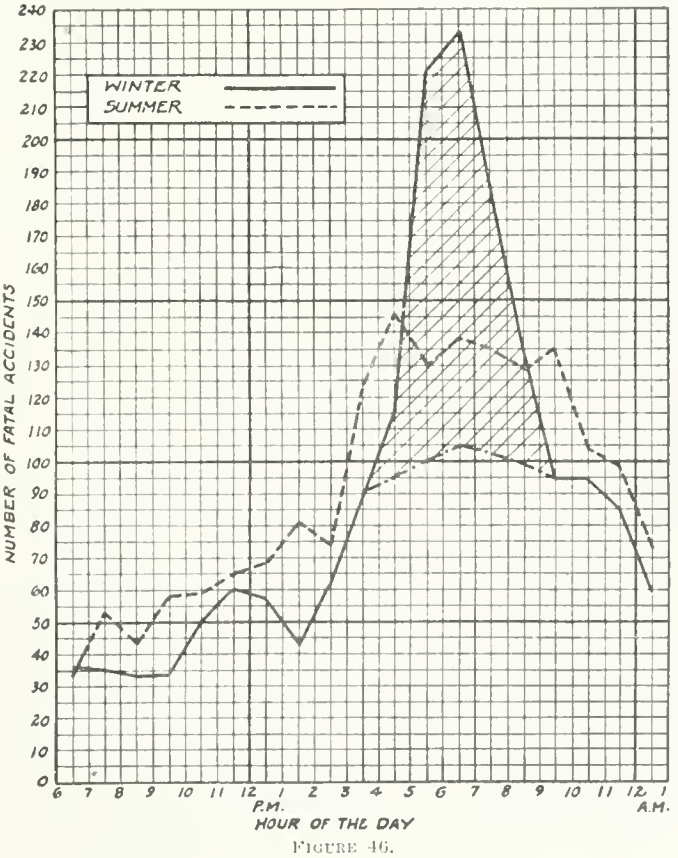

FIGURE 46.

the probability of their being killed or killing someone else while driving at night is many times as great as it is in the daytime. Lighting the highway will stimulate more night driving (particularly of trucks) and thereby relieve the daytime congestion.

(*c*) *Increased Comfort and Enjoyment of Night Driving.*—The strain of trying to see by inadequate illumination is terrific as experiments by Dr. Matthew Luckiesh have shown. It has been found that adequate illumination makes seeing easy, the driver relaxes, and the trip is changed from a nightmare to a pleasant experience.

(*d*) *Stimulus to Progress in Rural Electrification.*—The extensive development of highway lighting would assist greatly in the promotion of rural electrification. The poles specified in the preparation of cost estimates should be suitable for carrying a power-distribution circuit as well as the lighting system. The chief obstacle to the development of rural electrification will, therefore, be greatly reduced.

The present trend toward extension of highway lighting may be expected to receive added stimulus especially through the use of the recently invented brighter sodium lamp, the cheapening of electricity, and the pressure for rural electrification.

Sound

Public Address Systems.—In the field of sound there are to be found many developments of the laboratories of the electrical-goods industries. Foremost among these developments are the telephone, telegraph, and radio which are discussed in the chapter on communications. However, there are other applications in the field of sound which are also important; for example—the public-address system, which enables one man to speak with the voice of a thousand men, has unquestionably had its subtle social implications which are often overlooked. Formerly our men in public life were almost invariably endowed with leather lungs and a stentorian voice but now even the mild voiced little man can make himself heard to an assembly of hundreds of thousands, and by radio to millions.

When President Lincoln delivered his Gettysburg address, perhaps but a few hundred fortunate souls in the great assembly were actually able to hear his famous words; but when President Roosevelt delivered his inaugural addresses, all of the anxious thousands grouped about the Capitol (not to mention the additional millions of radio listeners) were able to hear his every syllable clearly and distinctly.

The ability of the public-address system to amplify the human voice is a tremendous factor in modern life. The control of mob action, particularly in times of emergency, means the saving of many lives, and the public-address system provides a means to this end, which has already demonstrated its effectiveness many times. Many Coast Guard cutters are now equipped with this device which greatly facilitates their rescue work by permitting the human voice to be heard clearly even above the roar of the sea and wind.

Cultural life has been enriched by the ability of the public-address system to carry the voice of lecturers distinctly to everyone in the assembly. Research engineers have adapted these same principles of sound amplification in the development of equipment which enables many deaf persons to hear, thus rehabilitating these unfortunate persons by permitting them to pursue their lives less hampered by their disability.

Electric Organ.—A recent achievement of our electrical research laboratories is the electric organ which is built to conform to established pipe-organ standards and, while it requires pipe-organ technique in the playing, has no pipes, reeds, or other vibrating parts. The instrument can never get out of tune and occupies about the same space as an upright piano, thus making it available to lovers of this type of music who live in small homes or apartments. Although this instrument may produce duplicate diapason and flute pipe tones, or orchestral strings and reeds, yet the organ itself contains no physical counterpart of any of these things. The initial cost is low relative to that of a pipe organ—the maintenance cost is that of a radio receiving set and the operating cost is less than 1 cent per hour. Many churches, schools, and private individuals are now using and enjoying this technological development. Perhaps this may mark the beginning of the mechanization of many of our other musical instruments. The least that can be said is that it has already revived interest to a very marked degree in hitherto expensive, and one might almost say declining, branch of musical art.

Burglar-Alarm Systems.—In nearly every type of our modern burglar-alarm system will be found a development of the laboratories of the electrical-goods industry. These systems usually employ the photoelectric cell actuated by either infra-red or visible light, direct closing of a circuit when a window or door is opened, or the magnetic field or capacitance effect which permit the detection of weapons or other large pieces of metal even when concealed. Electric burglar alarms may summon the police, ring bells, turn on floodlights, photograph the intruder, discharge tear or other gases; but the one duty which any of the systems performs is to reduce crime by providing a greater measure of safety for banks, factories, offices, homes—by making it increasingly difficult to commit a crime without immediate detection. Even after the crime has been detected and the criminal apprehended

these same alarm systems are employed in prisons to prevent his escape. Applied electricity has contributed materially to society in this respect by providing protection which otherwise would be impossible.

Other Devices.—Other applications in the field of sound include "talking books" for the blind, electric bells and chimes for our homes, and the electrically recorded and reproduced records for our amusement.

PART II

Productive Activities

Motors.—Probably no other electrical tool so symbolizes the idea of technological development in the electrical-goods industry as the electric motor. Yet one of the many things which the people of 50 years ago did not know and which has been in a large measure responsible for amazing industrial advance in all fields was the fact that the electric motor would bring cheap and efficient power to factories, revolutionize industrial processes, and perform virtually all the mechanical operations of whole industries. Today, 35,000,000 horsepower in electric motors turn the wheels of industry. And to industry this increasing efficiency meant better motors, more types of motors, lighter motors, and less expensive motors.

In 1900, one manufacturer[4] made five types of motors, and every one was custom built. Today, this same manufacturer with stocks in 29 warehouses, can supply immediately a motor for practically any application.

In 1900, a 5-horsepower polyphase motor weighed 716 pounds. Today, it weighs only 191 pounds, a reduction of 73 percent.

In 1900, that 5-horsepower motor occupied 19,700 cubic inches. Today, it takes up only 4,380, a reduction of 77 percent.

Today, the user without discount can buy three and one-half 3-horsepower motors for the same number of dollars that he would have had to pay for one 3-horsepower motor in 1900.

Of all the tools that ever came into the hand of man, electric motors and control have been among the greatest. Touching a button, the modern American workman sees electricity, through a motor, multiply his own strength a thousandfold and increase his producing ability in countless ways. By the improvement of this industrial efficiency it is possible to produce more things for more people at less cost, both the things which make for a more abundant life and things which assist us in the performance of our daily work.

Photoelectric Cells.—Silently into our lives is creeping a new technological brain-child whose ultimate social import cannot now be estimated. It is the photoelectric cell or electric eye as it is popularly known. A few of the functions which this apparatus is capable of performing:

A list of photo-cell applications[5]

Industrial:
- Reversing rolls in steel mill.
- Removal of soaking-pit covers.
- Control of cut-off saws.
- Furnace temperature control.
- Operating-limit switches for motor travel.
- Smoke indicators in smoke stacks.
- Detecting fine cracks in polished surfaces.
- Opening doors for hand trucks, motor trucks, etc.
- Automatic operation of mine ventilating doors.
- Warning signals on rolls in tire factory.
- Remote control of machines.
- Safety protection of machines.
- Detection of flaws in products.
- Alarm for water hardness.
- Analysis of card records.
- Fire alarms, smoke alarms.
- Paper-making machine—paper-break detection.
- Automatic weighing of batches.
- Chemical process control.
- Leveling elevators.
- Inspect storage-battery caps for vent holes.
- Sorting electrical resistances.
- Controlling thickness of enamel on wires.
- Rejection of nonsharp razor blades.

Food and chemical processes:
- Controlling levels of contents of tanks and bins.
- Drinking fountain control.

Food and chemical process—Continued.
- Cold-room door operation.
- Opening doors for animals (dairy, stables, etc.).
- Tooth-paste filling machines.
- Bottle fillers.
- Control of coffee roasters.
- Candling eggs.
- Moth control in orchards.
- Sorting raisins at 1,000 per minute.
- Sorting lemons, beans, etc.
- Eliminating green peaches from cannery stock.
- Sorting cigars.
- Control of acidity, alkalinity.

Light control:
- Schoolroom lighting.
- Shop and factory lighting.
- Electric signs.
- Flood lighting and decorative effects.
- Store lighting.
- Office lighting.
- Street-lighting circuits.
- Airports, aviation beacons.
- Lighthouses, range lights, markers, etc.
- Store and window lights, turned on at approach of passerby or patrolman.
- Parking lights on autos, automatically lighted at dusk.
- Riding lights on moored vessels automatically lighted.
- Signs along roadway, lighted on approach of car lights.

Counting measuring:
- Production lines (motors, automobiles, radios, refrigerators, etc.).

[4] General Electric Co.

[5] Excerpted from a list of compiled by Electronics McGraw-Hill, New York (October 1933).

Counting measuring—Con.
- Traffic in tunnels, on bridges, etc.
- People passing or entering (theaters, etc.).
- Animals, livestock, etc., in stockyard pens.
- Recording beats of master clock.
- Tabulating statistics, quantities.
- Measuring lamp candlepower.
- Astronomical measurements.
- Color measurement.
- Projectile velocities.
- Calipering steel balls.
- Boiler gage level alarms.
- Counting of printed items on cards, totalizing and analyzing.
- Counting ingress and egress of honey bees from hive.

Visual reproduction:
- "Facsimile" transmission of photos, maps, newspapers, etc.
- Enabling blind to read ordinary print.
- Photography of wild-animal life.
- Automatic photographing of sneak thieves, burglars, etc.

Safety uses:
- Protection of personnel operating punch presses and other dangerous machines.
- Protection of elevator doors, preventing car from starting unless all passengers are clear of threshold.
- Detection of icebergs, ships, etc., through fog.
- Safety doors in mines.
- Remote control of dangerous processes.
- Protection of jails, penitentiaries, etc.
- Protection of electrical machinery.
- Traffic-signal operation.
- Auto-speeding detectors.
- Street-lighting control.
- Detection of dangerous gases in tunnels.
- Hold-up protection, banks, etc. (closing of safety steel shutters).
- Fire alarms, smoke alarms.

Safety uses—Continued.
- Safety protection of oil burners.

Grading:
- Cigars.
- Tile.
- Beans, vegetables.
- Detecting missing labels.
- Inspecting tin plate.
- Calipering small parts.
- Color comparison.
- Adjusting auto head lights.
- Detecting flaws in products.
- Sorting checks and bills.
- Matching false teeth.

Traffic applications:
- Railroad signals (European).
- Street traffic lights.
- Elevator leveling.
- Elevator-door safety control.
- Elevator safety stops.
- Routing mail bags and letters.
- Counting street traffic.
- Checking up bridge-toll collections.
- Speeding subway traffic.
- Checking up theater patronage.
- Detecting dangerous gas in tunnels.
- Lighting air beacons and airfields.
- Controlling wind indicators from pilot vanes.
- Detecting automobile speeding by two photocells in roadway.
- Horse-operated signals for bridlepaths.
- Parking lights on automobiles lighted at dusk.
- Head lamps dimmed at approach of another car.
- Headroom alarms for tunnel and bridge approaches.
- Adjoining street signs and displays controlled by traffic light.
- Swing-bridge pin-lock safety indicator.
- Identifying and recording freight-car numbers.
- Checking auto crankcase oil at service stations.
- Adjusting illumination in vehicular tunnels.
- Calling gas-station attendant when car stops.

Printing, publishing, etc.:
- Automatic machine setting of type, from typewritten copy.
- Automatic control of accurate trimming.
- Accurate cut-offs for labels, bags, etc.
- Automatic stops for presses, preventing paper breaks.
- Adjusting density of printing.
- Counting of sheets and forms in binderies.
- Control of paper thickness and moisture during manufacture.
- Matching the colors of inks and papers.
- Controlling uniformity of color during printing runs.
- Providing permanent unfading color records.

Printing, publishing, etc.—Continued.
- Measuring glare and opacity of paper.
- Safety-first devices around presses.

Sound Production:
- Sound-picture recording.
- Sound-picture reproduction.
- Light-beam transmisston.
- The "talking book."
- Automatic merchandiser says "thank you" when purchase is made.

Scientific Instruments:
- Color analyzers.
- Color matchers.
- Light-intensity meters.
- Exposure meters.
- Combustion indicator.
- Measure instant of eclipse.
- Measure width of eclipse path.

A very good summary of some of the important functions of the photoelectric cell is furnished by C. C. Furnas in his book, The Next Hundred Years.

The photoelectric cell, or electric eye as the popularizers like to call it, can be made as sensitive as the human eye. It cannot be imbued with brains, but it can be adjusted (trained if you like) to perform routine tasks, reliably, consistently, cheaply. Suppose you are wrapping candy bars by machine. If you are making candy bars you would not think of doing it any other way. The wrapping machine probably moves so rapidly that you cannot follow its motion with the unaided human eye; so, as might be expected, it missteps occasionally and omits a wrapper. Girl inspectors might be counted upon to catch such omissions but a photoelectric cell is better. It never fails to see the missing wrapper. Photocells never get sleepy, no matter how late they may have been up the night before. By keeping the bars moving down a belt conveyor, and keeping them separated one from the other, the photocell equipment will accurately and mercilessly throw off every uncovered specimen.

Similar equipment sorts beans or cigars on the basis of color. Photocells can judge the color of textiles more accurately than can the human eye. They are being used to maintain lubricating oil at a given color and coffee at a uniform strength. Temperature is very important in the heat treatment of steel bars and electric eyes are being used to remove bars from reheating furnaces as soon as they reach the desired degree of redness. They are being used to guard prison walls and safes. By causing a bell to ring they warn a fireman when he is creating a smoke nuisance. They are used to regulate the thickness of paper in its manufacture and to stop the machinery and give warning if the paper breaks. They automatically level elevators at floor stops. They sort cards for tabulating machines and a practical device is available for apprehending speeders on the highways. They are certain, accurate, and not susceptible to arguments or feminine beauty. At bridle-path crossings they operate traffic lights for horses

but not for humans. The most common and simplest task of the cell is that of counting. They are used in factories to count almost every conceivable thing. The vehicles crossing the Ambassador Bridge at Detroit are so counted.

These examples are more or less random and do not cover the full range of possibilities. If you have never happened to notice these devices in operation, remember that they are very inconspicuous midgets and also they are as yet being used only in a very small fraction of the possible places. At a first guess I would say that there are at least a million workers in this country doing routine tasks of sorting, inspecting, or controlling, who could be cheaply and successfully replaced by devices actuated by photocells.

Even an ultraconservative estimate of the number of workers whose job could be done better and more economically by the photoelectric cell and associated equipment would probably be at least 250,000.

Industrial X-ray.—A new tool for industry and one which, while seldom heard of by the layman, is of growing importance because it not only provides greater safety to workers in many fields but also supplies a means of materially reducing much economic wastage. That tool is the industrial X-ray. Many research workers throughout the world are concentrating their attention on the industrial application of this science and have already pushed the boundaries so far that they themselves must sometimes view their achievements with amazement. Naturally work on the use of X-ray for the field of medicine is still being carried on and medical science, while still confronted with the enigma of cancer, has improved vastly its knowledge, applications and results with X-ray therapy, until the future seems certain to bring forth even greater triumphs in that field.

Industry within the past few years has come to appreciate the indispensability of this tool and yet, here again it is probable that an even more extensive use will be made in the future. Baffling problems have been solved with the aid of the X-ray "supermicroscope"; improved quality of products and rational standardization of manufacturing processes have resulted. There is a growing conviction that X-ray research and control methods can now and in the future be of invaluable service in the solution of problems of constitution and practical behavior of metals and alloys of every kind, of catalysts, textile fibers (cotton, flax, jute, ramie, sisal, hemp, silk, wool, rayon), rubber, balata, gutta percha, resins, varnishes, lacquers, paints, pigments, dyes, enamels, carbon black, inorganic and organic chemicals, waxes, greases, soaps, oils, liquids of all kinds, dielectrics, storage battery oxides, colloidal metals and gels, patent leather, glass and its substitutes, gelatine, adhesives, abrasives, lime, plaster of paris, cement, ceramics, sugars, starches, biological systems, coal, gems, and numerous other substances.[6]

Already X-rays are applied to detect flaws in our castings and welds which might so easily cause loss of life or serious injury—and certainly would prove a loss of time and money if the defective material was permitted to be made into a finished product.

Geophysical Apparatus.—The electric permanent waver may be considered as a divining rod but it certainly is not the only form of this long-sought-for device which our laboratories have produced. Mr. Donald G. Fink, in a paper published in Electrical Engineering, advises as follows:

Ever since man has known that mineral wealth lies hidden in the earth, he has been devising schemes for unearthing that wealth with the least possible effort. The search for a divining rod is, in fact, older than the equally dubious arts of alchemy. Only in comparatively recent years, however, have successful, and therefore accredited, schemes for divining the earth been developed. The success of these newer methods would not account for the high interest shown in them were it not for the real need that exists for some reliable method of subsurface exploration. This need is made only too clear by the fact that rocks that can be seen from the surface constitute only 1 percent of the total area of mining districts. Since by now this easily available 1 percent has been thoroughly exploited, the attention of prospectors has been turned to the remaining 99 percent which lies hidden beneath the surface—a portion none the less valuable, but vastly harder to explore. In the search for these hidden deposits, electrical methods are beginning to play an important part, and the importance of electricity in this field may be expected to increase.

Insect Killers.—The Rural Electrification Administration states that electric traps are rapidly becoming one of the weapons in the battle against advancing hordes of predatory insects. Light is the bait which attracts the pests while electricity, oil, or water is used to kill them. Entomologists and fruit growers have been frankly skeptical of the possibilities of such a device, feeling that there would be as much damage from killing beneficial insects as value in destroying harmful pests. However, extended experiments with light traps have indicated that these devices can be of great value against several very harmful species. Among these are the codling moth which lays eggs of the worm that attacks apples—the grape leafhopper which destroys grapes—the artichoke plume moth which makes artichokes wormy—dried-fruit insects which infest drying fruit in drying yards and warehouses—june beetles which attack nursery trees—and pestiferous insects such as gnats and mosquitoes. Students of the problem hope that further investigation and development in trapping insects by means of electricity will eventually do away with the use of

[6] Applied X-rays, George L. Clark, McGraw-Hill Book Co.

poisonous sprays which not only put the grower to the added expense of washing the produce for consumers' safety—but entomologists report, after a time the insects build up an immunity to them.

Industrial Lighting.—In the field of industry experiments indicate that it is possible to increase workers' production and at the same time reduce nervous fatigue by providing adequate illumination. For example, one group has determined that by the intelligent use of proper illumination it has been possible for them to increase production 41 percent on certain accurately measurable clerical tasks and at the same time reduce errors 71 percent. This record was obtained without working any physical hardships on the personnel and with only a very slight increase in capital expenditure for lighting equipment.

These improvements in artificial illumination have only begun, but already some of the benefits are being realized. Where people formerly used candles, tallow lamps without a chimney, or at best a whale-oil lamp which shed so little light, so costly, flickering, and reddish—perhaps one candlepower per room—they now have artificial illumination of many candlepower, cheap, pleasing to the eye, and efficient. The long happy evenings of today, so necessary for culture and recreation, in brightly lighted homes or places of entertainment, we owe to lighting research, as well as to increased wealth and education and shorter work. Further progress in lighting, in bottled gas (propane and butane) and especially in rural and urban electrification, will brighten the evenings in many homes and factories that are still dull.

Air-Conditioning.—The beneficial effects of air-conditioning to the physical well-being of man and as a contributing factor to the efficient performance of his daily work are now generally recognized and these same principles have been applied to industrial processes where, in the production of certain hygroscopic materials, the condition of the air is most essential.

An interesting application of air-conditioning was made when the owners of the Robinson Deep Mine, a gold mine near Johannesburg, South Africa, and one of the two deepest shafts in the world, decided to make the largest installation in the world. Their object is to increase their miners' efficiency by providing more comfortable working conditions, and thereby make it possible to extend their operations to depths at which it has heretofore been impossible to work because of the high temperatures and humidity. It is the belief of some economists that the application of air-conditioning to gold mines generally may so increase their production as to permit nations to return to the gold standard.

There are air-conditioned hospital rooms, tearooms, barber shops, dentists' and doctors' offices, conference rooms, offices, dress shops, department stores, restaurants, beauty shops, theaters, fur stores, millinery shops, clothing stores, and railway cars. Restaurateurs have definitely established the fact that the size of the diner's check (and no doubt his waistline) is increased if they cool and dehumidify their restaurants in the summer—dress shop proprietors find their sales increased and their damaged goods from perspiration stains decreased—and patients in hospitals are made far more comfortable through the same medium.

Air conditioning was credited with possibilities of importance for improving the health of persons living in American climate by several members of the medical profession who addressed the fortieth annual convention of the American Society of Heating and Ventilating Engineers and their contentions are borne out, at least in part, by the results of a survey made by the Philadelphia Electric Co. This survey discloses a reduction of 33 percent in lost time due to respiratory ailments among its employees during the first year of the study, and a further decline in lost time of 43 percent was recorded in the second year.

An interesting observation was made by Mr. Willis R. Gregg, Chief of the United States Weather Bureau, at the dedication of Frigidaire's air-conditioned house at A Century of Progress, when he said:

> The energetic, hard-hitting tactics of the northerner, who works hard and plays hard because the climate in which he lives inspires and invigorates him to greater activity, has had much to do with the development in our northern States of giant industries and other activities, with a resultant centralization of buying power.
>
> Is it too much to predict that air conditioning of the working and living quarters of other residents of more humid areas may cause more activity in those parts that will open up to use natural resources beyond our imagination?
>
> Or that the developments made possible by enabling men to work in strength-sapping climes will take up the employment slack and open up new channels of buying power.

Miscellaneous.—In the field of productive activities should also be included electric clocks and timing devices, the stroboscope for observing machinery in motion, the thermal couples for measuring temperatures, electric shovels, dredges, cranes, and electric furnaces. Likewise should be included the many electrical instruments; for example, the newly developed prerecording cathode-ray oscillograph which is capable of showing electrical events that occurred prior to the time of opening the shutter of a camera. The many applications of electricity in the productive activities in chemistry and metallurgy will be found discussed in the papers on those subjects.

Homemaking Activities

Electric Household Appliances.—Scores of technological developments of the electrical laboratories in the form of household appliances are making contributions to domestic comfort and happiness, and each year brings forth additional items in this field of labor-saving equipment. Household electrical appliances are not considered as luxuries but rather as necessities in efficient housekeeping. With the present low cost of the appliances themselves and the low cost of the electricity to operate them, it is really more economical to use many of them than to try to get along with old-fashioned methods and equipment on hand. One of the best examples of this is the electric iron, with which an hour's ironing can be done for the cost of approximately 3 cents. It is doubtful if we could buy other fuels to heat an old-fashioned iron at this price.

The estimated number of these appliances which have been sold in recent years is shown in the following table.

TABLE 19.—*Estimated sales of electrical appliances* [1] *(10 years, 1926–35)*

	Units
Cleaners, vacuum:	
Floor type	8, 999, 426
Hand type (7 years)	1, 388, 775
Clocks	13, 725, 000
Cookers and casseroles	1, 018, 000
Dishwashers	85, 500
Fans:	
Ceiling (9 years)	464, 904
Desk and bracket	7, 319, 105
Ventilating up to 16 in. (9 years)	239, 474
Heaters, radiators	3, 021, 611
Heating pads	4, 353, 800
Hot plates, grills	3, 607, 593
Ironing machines	889, 661
Irons	29, 772, 627
Mixers (5 years)	1, 596, 501
Oil burners	1, 031, 125
Percolators:	
Metal	5, 908, 438
Glass (3 years)	294, 000
Ranges	1, 242, 781
Roasters (1 year)	100, 000
Refrigerators, domestic	8, 255, 000
Sandwich toasters (2 years)	847, 600
Toasters	12, 341, 961
Waffle irons	5, 714, 524
Washing machines:	
Electric	8, 866, 071
Gas engine	912, 689
Water heaters (1 year)	150, 000

[1] Electrical Merchandising, McGraw-Hill (January 1936).

Recognizing the fact that a certain number of these sales as tabulated above represented replacements let us now look at some of the figures in a slightly different light:

TABLE 20.—*Estimated saturation of market for electrical appliances (United States,*[1] *Jan. 1, 1936)*

Appliance	Percentage of wired homes using	Number of wired homes using
Cleaners	48.3	10, 241, 579
Clocks	41.6	8, 813, 500
Cookers and casseroles	6.2	1, 325, 500
Heaters and radiators	18.4	3, 903, 506
Heating pads	17.0	3, 612, 966
Hot plates	14.9	3, 167, 347
Irons	97.2	20, 612, 616
Ironing machines	4.9	1, 031, 802
Oil burners	4.6	984, 995
Percolators—metal and glass	31.6	6, 697, 264
Ranges	6.8	1, 449, 250
Refrigerators	34.2	7, 250, 000
Toasters	49.8	10, 551, 283
Waffle irons	19.7	4, 167, 757
Washing machines	48.8	10, 346, 482

[1] January 1936 Electrical Merchandising, McGraw-Hill Publishing Co.

Thus it can be seen that while many wired homes—that is, homes now enjoying the conveniences of electricity for lighting—are now using one or more of these labor-saving appliances, we have only started on the path of improving housekeeping efficiency. The wonder is not that so many homes are now employing these electrical servants—but rather that so many are failing (usually for economic reasons) to utilize these conveniences. Again the laboratories are called upon for assistance and those laboratories are responding by producing new technological developments in machinery, methods, and materials—which ultimately mean lower production costs, lower sales prices—in other words increased production efficiency means more things for more people at less cost.

Books for the Blind.—Another important contribution to society which is being prepared in the laboratories is an apparatus which will permit the reading of ordinary books by the blind. At the present time all reading material for blind people must be translated into Braille characters or recorded on discs or film by the spoken word, but this new device which employs equipment not unlike some of our television equipment will open the doors of our libraries to those unfortunates who cannot see. It is not improbable that in the not too distant future the means of reading all books, magazines, and newspapers may be carried to the tips of the blind man's fingers from libraries to his home over the same circuits which now carry his telephone conversations.

Electric Clocks.—With the advent of "regulated frequency", now so generally maintained by power plants it has been possible to introduce into homes and offices at economical prices, electric clocks and timing devices. These timepieces, geared to the pulsations of alternating current are capable of maintaining time accurate to the smallest fraction of a second—which

certainly is in keeping with the present tempo of living. Electric clocks for the home, office, and factory are available in practically any style desired. We can secure alarm clocks, grandfather clocks, clocks which chime or strike ship bells—or just plain clocks—all accurate and all driven by electricity at an infinitesimal cost of operation. The growing use of electric clocks for simply telling accurately what time it is is indicated by the fact that 13,725,000 of them have been sold during the past 10 years (1926–35 incl.).

Electric Timing Devices.—Electrical timing devices, which have been used by industry for some time are now finding applications in homes. Electrical refrigerators can be defrosted automatically at regular intervals—the radio receiving set turned on at a predetermined hour in the morning (for that matter, it is even possible to preselect a whole series of radio programs on various stations at various times which will be presented in an orderly parade over a period of 12 hours)—the roast can be placed in the electric oven, and at a predetermined hour the temperature of that oven will be raised to the proper degree for cooking the roast, maintained for the period necessary to cook that particular roast, and then reduced to a point where the roast will be kept warm for the arrival home for dinner. For those people who, when away on vacations, have a greater feeling of security if lights are burning in several rooms back home—the electric timing device will not only turn them on regularly each evening, but will also turn them off again each morning. This electrical timing equipment so reliable in its performance performs duties (limited only in their application by human ingenuity) from starting the oil burner in the furnace room on cold mornings to the blowing of the factory whistle indicating that the day's work is finished.

Photoelectric Cell.—The photoelectric cell, or electric eye, while finding its principal applications in industry as previously described, also finds many applications in the home, for example:

Controlling uniform illumination in working rooms.

Monitoring oil-burner pilot flame, to operate safety valve.

Garage-door opener.

Alarms against burglars and trespassers.

Flood-lighting control.

Night-lights around house automatically turned on and off.

Automatic operation of door between dining room and kitchen.

Automatic opening of refrigerator door.

Motor shaking of furnace grates automatically cut off when bright coals pass into ash-box.

Window raising and closing mechanism.

Kidnaping alarms for nurseries.

Miscellaneous.—In homes electricity is used for cooking, water heating, dish washing, cleaning, laundering, air conditioning, and lighting. It is also used to operate electric door bells, telephones, radio, curling irons, electric lawn mowers, hedge clippers, and even the kitchen waste unit, or "electrical pig", whose purpose is to grind to a fine pulp all kinds of food waste, such as peelings, scrapings from dishes, bones—in fact, everything except bottles and tin cans, and, of course, the silverware—and dispose of them down the kitchen drain, where they are carried away in the general sewage system. Perhaps in time this "electrical pig" may seriously affect those persons now employed in the garbage-disposal industry. Truly electricity is constantly playing a greater part in our homemaking activities.

Leisure Time Activities

The two developments of the electrical goods industries which play the major roles in our leisure-time activities are probably the talking motion picture and radio broadcasting. However, it has been seen that lighting by electricity has also contributed materially to these activities. Efficient outdoor floodlighting has made possible baseball, football, tennis, and golf during the hours of darkness, while efficient lighting indoors had made reading, bowling, billiards, ping pong, and many other indoor leisure time activities popular, particularly during the winter months. The modern theater would lose much of its present effectiveness and enjoyment without electricity.

The photoelectric cell assists in recreation with such duties as timing horse races, timing athletic contests, marking foul line for bowling alleys, and the timing of golf club swings.

Automobiles depend upon their electrical ignition and lighting systems to help us move about in pursuit of recreation and approximately 3 million automobiles are equipped with radio receiving sets to entertain us as we go. Electric traffic lights and highway lighting permit us to drive with greater safety and then return home where the ever-alert photoelectric cell may open our garage doors for us.

Other Activities

Electricity in the Field of Medicine

Lighting.—Illumination engineers are constantly on the lookout for better means of brightening dark places. Shadowless lighting for the operating rooms in hospitals has already been provided and work is now being pressed forward which shows promise of providing additional lights (probably of ultra-violet) not for illumination but for the constant sterilization of the air about the operating table, thus removing the

danger of infection from that source. If the present experimental work is declared successful by the medical profession, it is well within the bounds of probability that similar lights will be introduced into the intake ducts of our home and office air-conditioning apparatus, thus providing a means of reducing such frequent infections as common colds, etc. Another development of importance to the field of medicine is the tiny "grain of wheat" incandescent lamp which is widely used in various types of instruments.

Electrotherapy.—Many developments are being made in the laboratories of the electrical goods industry which are finding applications in the field of medicine in assisting doctors to cure human ailments. Needless to say, many medical research groups receive this equipment with enthusiasm and are pressing ahead with these new tools of their profession towards greater goals of achievement. Many reports are received which seem socially so significant that we can but wonder what may be the ultimate effects of this development. In this case the research engineer can only play the role of the tool designer; it is for the medical profession to say what may be accomplished through the use of electrotherapy.

Of special note is the recent announcement of the use of ultra-short-wave therapy as a successful means of combating focal infections and acute inflammatory processes. In his recent study Ultra-Short-Wave Therapy (1936), Dr. William H. Dieffenbach differentiates between diathermy and ultra-short-wave therapy as follows:

Diathermy

I. Both produced by high-frequency currents.

II. Long wave length.

III. Frequencies of 300,000 average; maximum of 1,000,000 per second.

IV. Applied direct on tissues after lubrication.

V. Effects secured through actual contact dispersion of current.

VI. Current responds to Ohm's law and can be measured in amperes or fractions thereof.

VII. Current follows line of least resistance, along blood vessels, lymphatics, fats, and superficial tissues. Bones, cartilage, and deeper tissues not much affected.

VIII. Dosage varies from 10–40 minutes 500–1,500 MA. Repetition can be had daily until improved.

IX. Contra-indicated in infections and septic lesions. It appears to spread infection along blood paths rather than retard or inhibit same.

X. In D'Arsonval couch or chair can affect whole organism and relieve toxemia, increasing metabolism and elimination.

XI. In form of fulguration and coagulation, knife and cautery, is used to destroy the local lesions.

Ultra-Short Wave

I. Both produced by high-frequency currents.

II. Short wave length

III. Frequencies:

	Per Second
3 meter	100,000,000
4 meter	75,000,000
6 meter	50,000,000
10 meter	30,000,000

IV. Applied with dielectric and air space—½ inch to 3 inches from tissues.

V. Effects secured through an electromagnetic field produced between the electrodes.

VI. Cannot be measured; amperages at control vary; patient must be tuned in and joule units noted. Does not respond to Ohm's law.

VII. Being placed in an electromagnetic field, the tissues are evenly penetrated. Distance from skin affects deepest structures, bones, and cartilage are evenly affected.

VIII. Time dosage from 10–30 minutes maximum; electrodes being placed depending upon depth of tissues—the dosage can be repeated daily and as improvement is noted, semiweekly and weekly.

IX. Has proven a specific in local or localized infections—furuncles—carbuncles—empyema—abscesses and acute inflammatory lesions.

X. At present is used over focal areas only. A course of a nerve can be treated at different stations in divided doses. Without solenoid attachment can be applied over larger parts of body.

XI. Is not at present generally used for destructive purposes, although attachments for fulguration, etc., can be made. After use of deep X-ray, it is employed to produce tissue response and sclerosis of treated tissue.

In his conclusion Dr. Dieffenbach points out:

> Many surgeons, gynecologists, and specialists as well as general practitioners, will in the near future, find their practice greatly aided and modified by the new ultra short wave treatment. In combination with Dr. Hartman's recent discovery of desensitizing teeth for dental operative work, the dental profession will also be obliged to adjust and modify its technique for, if the results noted on apical abscesses, pyorrhea, and granulomatous lesions are fully confirmed, the removal of infected teeth will become less frequent.

The usefulness of applying heat is widely recognized in the medical profession. Of the various forms of electricity used at present probably the best known is diathermy. It has the advantage of being easily controlled and being readily applied within the tissues almost at any chosen point. Diathermy is being subject to extended use especially in the following cases: Gonorrheal epididymitis, high blood pressure, neuritis, arthritides, and pneumonia. While no uniformity of results has been received from the treatment of these diseases, it is to the medical profession that we must look for the future development in this field of treatment of disease which seems to offer possibilities of vital importance to our entire social structure.

Miscellaneous.—The X-ray has long been a trusted tool of the doctor and other technological developments of the electrical goods industries which have also assisted him in the performance of his duties are lighting, air conditioning, electric sterilizers, electric stethoscopes, and even the electric elevators which permit him to move his patients with greater facility.

Decoration.—Electricity has played its part in the field of art and decoration as can be readily appre-

ciated by the lighting of our store windows, our electric signs, our flood-lighted buildings, monuments and even the beauty of nature itself. The modern beauty parlor, which certainly has contributed materially to our present social scheme of things, contains many appliances which represent the technological developments in the electrical goods industries. Hair driers, electric curling irons, ice from electrically operated refrigerators for cold compresses, electric skin patters, sunlight lamps, electric clippers, electric light and heat ray baths, body exercisers, warming pads, vapor heaters, and the electrically heated permanent waver—all operating in an air-conditioned atmosphere.

In homes decorative electric fireplaces and electrically lighted Christmas trees are found. In art galleries and museums lighting is used effectively to display art treasures. More electric lighting is being constantly used for artistic purposes.

Conclusion

The preceding discussion has treated comparatively few of the technological developments of the electrical goods industries both in the field of helping us to a more abundant life and in the field of assisting us in our "daily work." So diverse and widespread are inventions in these fields that it is difficult to see far ahead. Unlike inventions in some other fields, devices in the electrical goods industries tend to be particularistic in their application rather than cumulative in their effect. Thus, these industries seem to be subject to the factor of rapid change. Likewise, the future of these industries is so linked up with developments in rural electricity, the extension of transmission lines, and the cheapening of electricity that the extraordinary and extensive results which may ensue cannot be readily anticipated.

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The following sources have been used freely in the preparation of this paper, and to their authors the writer expresses deep gratitude and sincere admiration. If in some cases he may have literally taken their ideas, their words, their phrases, their sentences, he begs their indulgence. Ultra-Short-Wave Therapy, William H. Dieffenbach, M. D., B. Westermann Co., New York; The Science of Radiology, authorized by the American Congress of Radiology, Otto Glasser, Ph. D., editor, published by Charles C. Thomas, Baltimore, Md.; Short-Wave Therapy, Dr. Erwin Schliephake, Privatdozent for internal medicine at the University of Jena—authorized English translation by R. Kind Brown, B. A., M. D., D. P. H., The Actinic Press, London; Applied X-rays, George L. Clark, Ph. D., McGraw-Hill Book Co., New York; The Next Hundred Years, C. C. Furnas, Reynal & Hitchcock, New York; The Electric Home, E. S. Lincoln, The Electric Home Publishing Co., New York; various issues of Electronics, McGraw-Hill, New York; various issues of Electrical Merchandising, McGraw-Hill, New York; various issues of the Journal of the American Medical Association; various studies and publications of the larger electrical manufacturers, particularly the General Electric Co.; various publications of the United States Department of Commerce; Technological Changes and Employment in the Electric-Lamp Industry by Witt Bowden of the United States Bureau of Labor Statistics, Washington, D. C.; Air Conditioning for Comfort and Health, Past—Present—Future, by Elliott Harrington, Journal of the Franklin Institute, vol. 215, no. 6; various issues of Electric Refrigeration News, Business News Publishing Co., Detroit, Mich.; and Refrigeration and Air Conditioning Market Data by the Business News Publishing Co., Detroit.

VIII. METALLURGY

By C. C. Furnas[1]

Summary

About 93 percent of the world production of metals is iron and steel, the remainder being divided among the various nonferrous metals. The ratio of nonferrous to ferrous metals produced is slowly rising. The real prices in terms of purchasing power of the dollar of metals in the United States over the past two decades have been constant or slowly dropping. This trend will probably continue for some time. The quantity of metals produced in normal times is increasing to a certain extent but there is no great boom in sight. Labor-saving devices and processes are increasing in use in the metal industries and will have a decided effect on technological unemployment in the future. Metal products are progressively being improved, particularly in the matter of corrosion resistance and strength. There are still a great many possibilities of developing new metallic alloys. At the present time there is a great need for standardization of metallic alloys and their properties in order to cut down the number of alloys which are being manufactured. New high-speed cutting tools are going to speed up manufacturing processes well above their present rate. There are several new processes in development stage which will probably cut costs and improve quality of metal products. Aluminum and magnesium will probably be used much more in the future than they are now. The price of both will probably come down. The most likely field for increased use of metal is in prefabricated houses but this market will develop slowly. The metal industries are requiring an increasing number of high-caliber technically trained men. Our position in regard to "strategic" metals is improving because of research which has developed new ways of obtaining metals from low-grade ores. This country has lagged behind foreign nations in the pursuit of fundamental research. There is a great deal of need for the fostering of more research in this country on the fundamental metallurgical problems.

A View of the Field

Metals were first looked upon as materials which could be beaten into sharp-edged instruments that were very useful in putting one's enemies in their proper place, under the ground. As man advanced, he began to use metals for decorative and monetary purposes. Eventually the field expanded until man now uses metal for everything from probing within his own brain case to flying 14 miles above the earth's surface.

Of the 92 elements of the earth, 68 may be (although not indisputably) classed as metals. Of this number at least half are, or have possibilities of being, commercially important, although only a dozen are used in sufficient quantity to be classed as structural materials. To state that the metals are the material backbone of the modern world is to repeat for the millionth time a well-worn chestnut, so that theme does not need to be enlarged upon.

Metallurgically-minded individuals would like to believe that the march of civilization would have been accelerated a hundred fold if the ancients had pursued philosophy less diligently and had turned their investigative efforts toward experimental work on ways and means of winning and working the metals. This might be true, but had that been the case our world would probably have lost whatever eternal virtues there may have been in ancient civilization, for steam turbines hardly fit in with the Age of Pericles, and Fords in the Forum would have been the height of incompatibility. However that may be, the past is behind us and is far less important than the road ahead. We are in the midst of an age of metals, but have only made a bare beginning in utilizing them for our material benefit. The important task now is to improve metallurgy as rapidly as possible, so that we may rise to higher levels of material well-being.

Metallurgical progress through the past ages was pitifully slow because nearly all of the metals, with the exception of the relatively rare and noble trio, gold, silver, and platinum, usually occur in nature in combination with other chemical elements and consequently, as found, have no metallic properties. To break these chemical bonds and free the metals into their elemental state was, to the ancients, a mysterious process, difficult to perform. Not until chemistry began to grow into an exact science did the metallurgist know what he was trying to do and begin to make new contributions to society.

Obviously, if the natural state of most metals is in chemical combination with other elements, nature opposes these changes which the metallurgist wishes to bring about. Our civilization is on a meta-stable basis, for if nature is allowed to have her way, the suspension bridge becomes a pile of rust and the copper power line a strip of greenish powder stretching across the landscape. Modern civilization depends not only on winning the metals, but also on keeping them

[1] Associate Professor of Chemical Engineering, Yale University, author of The Next Hundred Years.

from reverting to their natural state. The most permanent structures are still those that are made from masonry.

Since metals cannot compete with rocks in the matter of permanence, their virtues must lie in other fields. Some metals are primarily important because of unusual strength. They are readily workable and have unique possibilities of fabrication. They can be drawn, rolled, hammered, cut, machined, planed, forged, or cast into the most intricate shapes. After fabrication they can be "heat treated" to increase the strength, hardness, or toughness by many fold. Some types of metals are important not because of strength, but because of marvelous ductility. Others, such as the bearing metals, are useful because they are soft and readily conform to the irregularities of a hard rotating shaft. Copper, and to an increasing extent, aluminum are highly important because of their electrical conductivity.

Though some metals have properties which make them useful for a number of things, obviously no one material can be used for everything. Fortunately, it is possible to combine two or more elements to make a new material which may be entirely different from the constituents. Ordinary hard steel, for instance, is a combination of pure iron, which is itself quite soft, with a small amount of carbon, which is usually soft, even fluffy. Suppose other metals should be added, what would the resulting material be like? In the 1820's, a young man, Michael Faraday, began to answer that question, scientifically and systematically. It was metallurgy's loss that after a few years he turned his marvelous brain to a study of electrical phenomena. His metallurgical studies lay buried in the dust for 60 years before anyone recognized their importance. Four generations of physical metallurgists since Faraday have only been able to probe a small portion of the field. While a century ago the metallurgical materials, exclusive of the noble metals, were wrought iron, cast iron, steel, copper, brass, zinc, bronze, lead, tin, and not much else, there are now at least 5,000 alloys in industrial use. That is almost equal to the number of stars visible to the naked eye and, like the stars, only a few of the alloys are named. Most of them are merely numbered. The possible number of combinations of metallic materials are almost limitless, certainly numbering into the hundreds of thousands, though probably only a small proportion of them will be found to possess distinctively useful properties. However, with an almost infinite number of materials, an immense number of possible uses may be expected. The metallurgist has probably found only a small proportion of them.

Direct Results of the Introduction of New Metals

The most obvious result of the use of new metals has been the production of mechanisms which it would have been impossible to produce even at unlimited cost in the early days. The best known example, of course, is the automobile. It would be impossible to construct a machine of cast iron which could withstand the wear and tear of even the most carefully handled motor car. When one considers the amount of oscillation which a front axle undergoes, he can well believe that it takes extraordinarily strong steel to stand the punishment. The gears, camshafts, and various other parts of the car must withstand such stresses and shocks that they must be made of steels of a quality that was absolutely unobtainable a century ago. The various makes of the average-priced automobiles of 1935 contained 83 different alloy steels.

Though airplanes were first made without any appreciable quantity of metals outside the engine, the modern, efficient, speedy plane is becoming almost completely a metal mechanism. This is a direct result of the development of the light aluminum alloys of the duralumin type of which aluminum is the chief constituent. Obviously, an airplane made of an ordinary grade of steel would be an impossibility, so that we can say that the modern airplane has been made possible by the development of the light alloys. Steels have now been developed which give as much strength per pound for a given shape as the aluminum alloys, and airplanes with stainless-steel wings are now being manufactured and used.

The last 20 years have seen a tremendous increase in the temperatures and pressures used in chemical industries. The chemical engineer has designed equipment which called for steel that would retain its strength and resist corrosion at a bright red heat. After a great deal of research the metallurgist has supplied such materials and has thus revolutionized the petroleum industry as well as many a process of chemical manufacture.

These three examples show how new materials make new equipment possible. Hundreds of technological developments can be attributed to the metallurgist's improvements in his materials. How many more improvements he can make, only research can tell. Certainly all those who expect to make metallurgical advances in the future must put a great deal of time and money into research.

The Increasing Efficiency of Production

As in every other line of industrial activity, the most noticeable trend in the metallurgical industries since the beginning of the present era has been the increased

efficiency of production, brought about largely by the substitution of machines for hand labor. In the early days, the blast furnaces for the production of pig iron from ore were small affairs which would turn out perhaps 5 to 10 tons of molten metal per day. There are now several blast furnaces in operation which, using no more men than formerly, can turn out as much as 1,000 tons of iron every day. The trend of decreasing man-hours per ton of metal produced is shown in figure 1. The upturn of the curves in the last few years is due to the operation of plants much below full capacity because of business conditions. The bulk of the product of the blast furnaces, pig iron, is further refined to make the stronger and more useful product, steel. Early steel making was revolutionized by the advent, in the middle of the last century, of the Bessemer process for the making of steel from molten pig iron by the simple expedient of blowing air through the metal. This caused a tremendous decrease in the cost of the production of steel, but the product was not of high quality and the raw materials used had to be carefully selected. Consequently, the Bessemer process was largely supplanted in later years by the open-hearth process invented by the German-born English subject, Siemens. This was more expensive and time consuming, but gave a very much better product and it permitted the use of a greater variety of ores. The proportion of steel produced in the United States by the various processes as the years have progressed is given in table 21. The columns reveal not only the battle between Bessemer and open hearth, but also a losing fight in the specialties and high-quality field, namely, crucible versus electric steels.

TABLE 21.—*Production of steel (ingots and castings) by grades, percentage or total production* [1]

Year	Open hearth	Bessemer	Crucible	Electric	Year	Open hearth	Bessemer	Crucible	Electric
1890	12.0	86.3	1.66	.....	1926	84.3	14.4	.03	1.4
1900	33.4	65.6	1.0	.....	1927	84.8	13.7	.02	1.5
1910	63.2	36.1	.5	0.2	1928	85.6	12.8	.015	1.6
1915	73.7	25.8	.3	.2	1929	85.7	12.6	.102	1.7
1920	77.5	21.1	.2	1.2	1930	86.0	12.4	.006	1.5
1921	78.8	20.3	.04	.9	1931	86.9	11.6	.006	1.5
1922	82.3	16.6	.08	1.0	1932	87.0	11.2	.005	1.8
1923	79.9	18.9	.10	1.15	1933	87.8	10.4	.003	1.8
1924	83.3	15.5	.06	1.1	1934	90.3	8.3	.002	1.4
1925	83.8	14.8	.04	1.4	1935	90.0	8.4	.002	1.6

[1] From Annual Statistical Report of the American Iron and Steel Institute, 1935.

Despite the ascendency of the more time-consuming open-hearth process, there has been a general downward trend in the man-hours required per ton of steel, as shown in figure 47. If it is assumed that the ideal of any industry is to produce the maximum amount of material for an hour of labor, it would be worth while to investigate the possibility of still further increase in production per man-hour in the steel industry.

In order to view the picture as a whole it will be best to summarize the kind and quality of material which goes into the production of a ton of finished steel. Table 22 shows the materials which enter into the average ton of steel in modern practice. In table 23 data are given on the number of man-hours required for each operation involved in the production of a gross ton of pig iron.

TABLE 22.—*Estimated average quantity and relative importance of basic materials required per gross ton of finished steel product* [1]

Basic material	Gross tons	Per-cent	Basic material	Gross tons	Per-cent
Iron ore	2.196	36.6	Scrap iron and steel	0.594	9.9
Flux	.666	11.1	Metals and alloys	.114	1.9
Coking coal	1.506	25.1	Miscellaneous	.192	3.2
Other fuel (for power and heat)	.732	12.2	Total	6.000	100.0

[1] From Monthly Labor Review, May 1935, p. 1155.

TABLE 23.—*Labor requirements per gross ton of pig iron* [1]

Mining:	
Iron ore, including cinder, etc	1.8
Coal	2.4
Fluxing material	.2
Total	4.4
Transportation:	
Iron ore	2.0
Coal	1.6
Fluxing material	.5
Total	4.1
Manufacturing:	
Blast furnace operation	2.3
Converting coal to coke	1.2
Total	3.5
Grand total	12.0

[1] From Monthly Labor Review, May, 1935, p. 1155.

After the metal has been made into iron it is usually converted into steel, but there are many types of products into which it may go. Table 24 shows the disposition of the expenditure of labor in the production of steel of various shapes. This table includes in the total amount of labor required that which has gone into the manufacture of the pig iron.

It is obvious from figure 47 that if there is to be any significant further decrease in the number of man-hours required for the production of steel, it will probably come in that part of the operations which is concerned with the making of the steel from pig-

iron and its later fabrication into shapes; for on the average about 12 man-hours are required to produce a ton of pig iron, while it takes about 35 man-hours per ton of steel after the pig iron has been delivered. This figure is for average production and does not include pipes and tubing or special shapes.

TABLE 24.—*Average man-hours required per gross ton of steel products, with plants operating at 55–60 percent of capacity* [1]

Item no.	Product	Total	Number of man-hours required				
			Extraction	Transportation	Coke manufacture	Manufacture	Administration
	Average, all products	53.00	7.75	8.00	1.50	34.43	1.32
1	Billets and slabs	29.03	6.69	6.48	1.33	13.98	.55
2	Structural shapes, rolled	33.91	7.27	7.04	1.45	17.46	.69
6	Standard rails	38.54	7.80	7.55	1.55	20.82	.82
9	Wire, drawn	51.19	7.17	8.04	1.43	33.23	1.32
13	Pipe and tubing	62.72	9.00	9.02	1.80	41.26	1.64
18	Fabricated structural work	84.00	8.00	8.95	1.60	62.95	2.50

[1] The table included 18 products on which the average is based. From Monthly Labor Review, May 1935, p. 1155.

It was not until recent years that any comprehensive study was made of the relation between the percentage of capacity at which a mill was operating and the number of man-hours required for the production of a unit weight of product. Unfortunately, this study was made during a period when no mills in this country were operating at full capacity, so that no exact figures are available for more than 60 percent of full operation. Table 25 shows the result of this survey and gives a rough idea of the increased man-hours required for a decreased production in a given plant. The figures are for 20 to 60 percent of total productive capacity. The increasing efficiency

TABLE 25.—*Variations in man-hours required in manufacturing a gross ton of finished steel products at specified rates of plant operating capacity* [1]

[Based on statistics of American Iron and Steel Institute]

[Average for all finished steel products]

Percent of total plant capacity	Actual average man-hours		Index of man-hours required	
	Manufacture	Administration	Manufacture	Administration
55–60	34.43	1.32	100	100
50–55	36.15	1.47	105	111
45–50	38.22	1.73	111	131
40–45	40.63	1.94	118	147
35–40	42.34	2.25	123	170
30–35	43.73	2.65	127	201
25–30	45.10	2.92	131	221
20–25	46.48	3.26	135	247

[1] From Monthly Labor Review, May 1935, p. 1155.

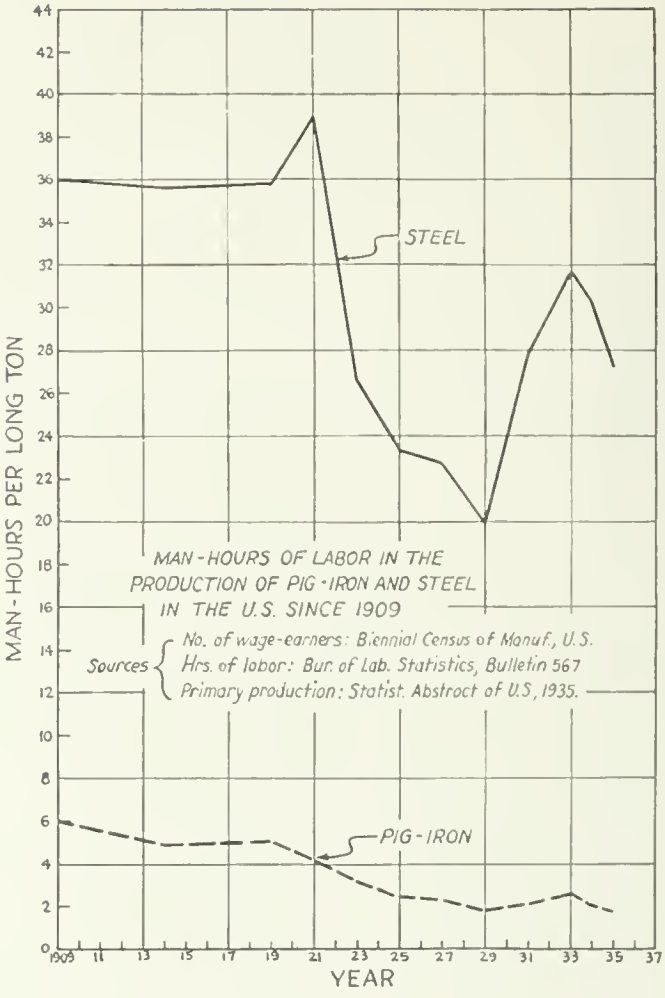
MAN-HOURS PER LONG TON
YEAR
STEEL
PIG-IRON
MAN-HOURS OF LABOR IN THE PRODUCTION OF PIG-IRON AND STEEL IN THE U.S. SINCE 1909
Sources
No. of wage-earners: Biennial Census of Manuf., U.S.
Hrs. of labor: Bur. of Lab. Statistics, Bulletin 567
Primary production: Statist. Abstract of U.S., 1935.

FIGURE 47.

of labor with increasing capacity is exactly the trend which would be expected, and probably is no more characteristic of the steel industry than of any other.

There is every reason to believe that in the future the average figure of 35 man-hours per ton of finished steel produced from pig iron will be materially reduced. In 1929 there were 1⅛ billion man-hours consumed in the production of steel. Any item which makes a very large percentage change in this figure will undoubtedly have a distinct effect, at least of a temporary character, on technological unemployment.

In the early days of the making of steel shapes it was customary to roll into billets and slabs, then take these materials and reheat them at a later time and roll them down into the particular shapes desired. There is a certain tendency to perform more of the operations without these cessations of processing which necessitate intermediate reheating. In former years it was necessary not only to reheat the material one or more times during the production of thin steel sheet but it was also necessary to use a great deal of hand labor in

feeding the sheet which was being rolled from one mill to another. These hand operations and the reheating are being rapidly eliminated by the process of continuous rolling from the steel ingot to the finished sheet.

This development of the continuous strip mill for the producing of steel sheets appears to be a result of customer pressure, particularly from the automobile industry. We have gone through an era of skyscraper and railroad expansion demanding heavy structural types of steel. The trend today has shifted toward light sheets of deep drawing steel that can be fabricated rapidly into such articles as automobile fenders, automobile tops, beer cans, kitchen stoves, refrigerators, enameling stocks, and ice-cream containers.

A development has taken place in the field of making castings which is roughly parallel to the continuous rolling of sheet steel. The Crane Co. and the Westinghouse Air Brake Co. years ago made use of a continuous process for making iron castings. The Ford Motor Co. has instituted a system of continuous pouring of castings. Molten iron is taken directly from the blast furnace and after passing through an intermediate mixer and electric furnace is poured into cylinder block molds on a production line. Several thousand cylinder blocks, as well as over a thousand tons of other castings, are made in this way every day. There is a large saving in labor as well as in fuel. It is another instance of what may be accomplished by a simple synchronization of industrial processes.

The increased amount of production per man-hour in the iron and steel industry is paralleled by that in the nonferrous field. In figure 48, the man-hours required for the production of a ton of lead, copper, and zinc are given from 1914 to 1933. There the very decided downward tendency shows itself again with, as might be expected, the up-turn after 1929 due to the decreased quantity of production. The relative tendency of decreasing man-hours is shown in figure 49 for iron, steel, and the three principal nonferrous metals.

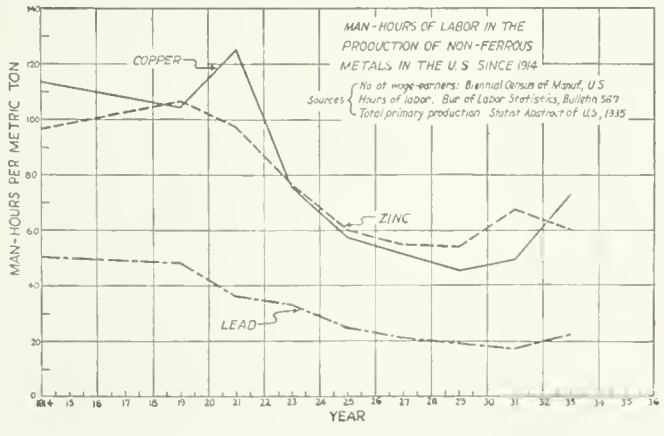
MAN-HOURS OF LABOR IN THE PRODUCTION OF NON-FERROUS METALS IN THE U.S. SINCE 1914
Sources { No. of wage-earners: Biennial Census of Manuf., U.S.
Hours of labor: Bur. of Labor Statistics, Bulletin 567
Total primary production: Statist. Abstract of U.S., 1935
COPPER
ZINC
LEAD
MAN-HOURS PER METRIC TON
YEAR

FIGURE 48.

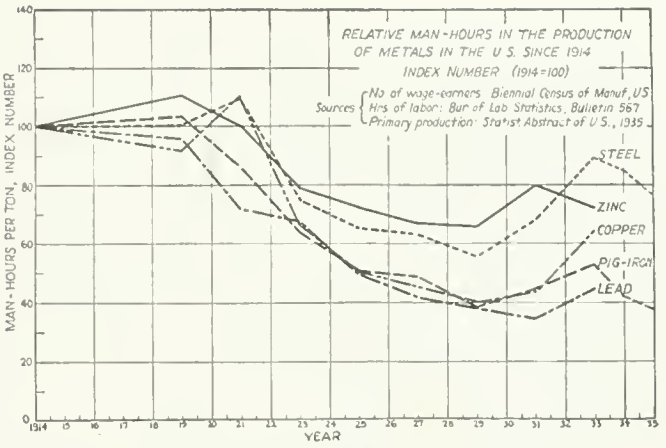
RELATIVE MAN-HOURS IN THE PRODUCTION OF METALS IN THE U.S. SINCE 1914
INDEX NUMBER (1914=100)
Sources { No. of wage-earners: Biennial Census of Manuf., U.S.
Hrs. of labor: Bur. of Lab. Statistics, Bulletin 567
Primary production: Statist. Abstract of U.S., 1935
STEEL
ZINC
COPPER
PIG-IRON
LEAD
MAN-HOURS PER TON, INDEX NUMBER
YEAR

FIGURE 49.

The general downward tendency will probably continue for some time to come, despite the fact that there is a growing demand for an increase in the number of kinds of product.

There seems to be little doubt that one of the results of future metallurgical developments will be an increasing amount of technological unemployment among the workers directly concerned in the production of metal and fabrication of its products. It seems doubtful if this can be remedied by increased production and consumption. This will be particularly true in the nonferrous fields where the raw materials used are relatively expensive, for there is not a single plant in the world engaged in the fabrication of articles of copper, brass, lead, zinc, etc., which is completely up to date in the utilization of labor-saving devices. As plants become completely modernized, and eventually they will, there will be more men and women thrown into the lists of the unemployed. Organized labor will oppose such advances. This will delay, but not stop them. This item of future technological unemployment is mentioned here merely to point out again that we as an industrial society have found no fundamental solutions for the problems raised by the replacement of men by machines. This statement is made with full knowledge of the fact that increased consumption of goods and increased use of personal services do tend to furnish employment for those displaced by machines. It must be considered that the ideal society would be one in which as much of the drudgery as possible would be performed by machines but in which no man or woman would be denied a means of livelihood. It is useless to evade the issue by postponing the use of labor-saving methods and devices. Metallurgical industries, and all others, must look ahead to the day when machines and not men will be the principal organs of production and they must answer the question: How is the average man to make a living?

Trends in the Quantity of Metals Produced

If one will plot the trend of metal consumption over the period of a century, he will see a tremendous increase in the use of all metals, either *in toto* or *per capita*, between the years of 1836 and 1936. The tendency of the optimist, then, is to extrapolate the rising curve for another 100 years and to view the future with unbounded enthusiasm. However, if one looks at the matter in more detail, he has little reason to believe that this curve will continue to rise in the future as it has in the past.

The picture of the production of iron and steel is shown at close range in figure 50. It is very interesting to note that the figure of consumption in 1929 is about 25 percent above that of the consumption in that highly productive and destructive year of 1917. If the growth curve between 1922 and 1929 is considered normal, then it would seem as if we have only begun to enter the field of utilization of steel. Unquestionably, the precipitous decline of the curve which ends at the bottom of a precipice in 1932 (see fig. 50) can hardly be considered normal. We will use more metal in the future than in the past, but it is very doubtful if the upward swing since 1932 means that we are going to continue the rapid rise of the 20's.

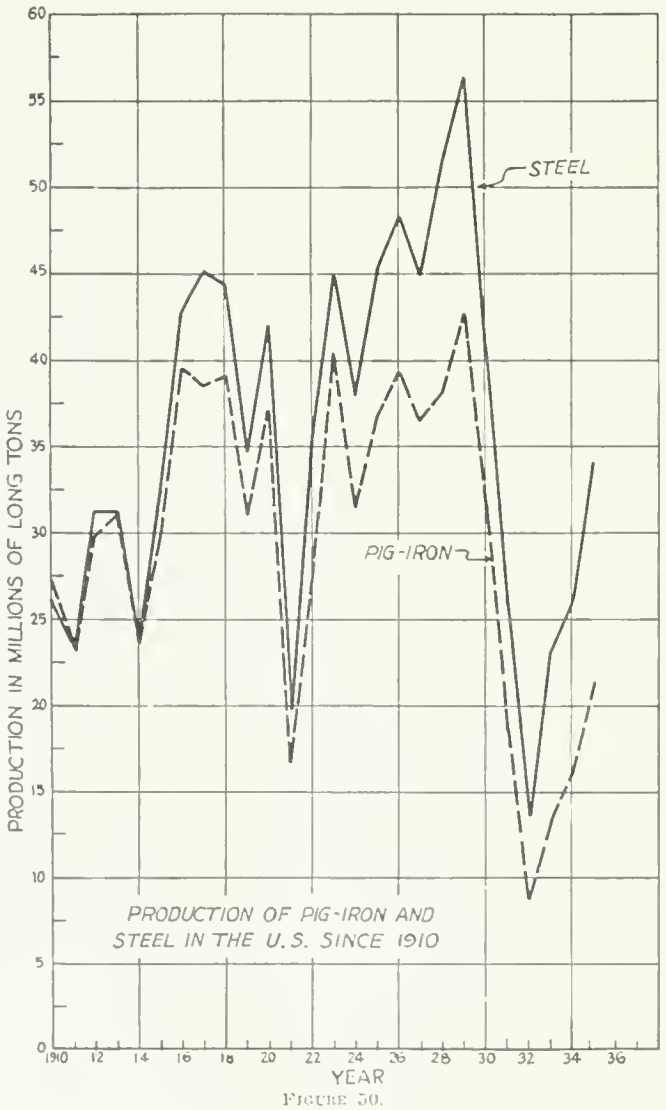

FIGURE 50.

It should be pointed out that there are at least three underlying and, to some individuals, distressing tendencies which tend to cut down on the amount of metal needed even though we should rise to higher and higher standards of living and thus use more and more metal in our daily lives. These three items are: First, the forthcoming static, if not actually decreasing, population with not only its decreasing numbers but also its increase in the average age and hence in the tastes and needs of the average American. The second important item is the increasing use of secondary metal, more commonly known as scrap. The third item is that the quality of the metals which have been won from the earth is, through the hands of the physical metallurgists, being continually improved. This means longer life for the materials because of improved strength and corrosion-resisting characteristics. These items will be discussed in more detail later.

Though iron and steel now account for about 93 percent of the metal produced, we would never have progressed very far had we not had the nonferrous metals to call on. The data on production of the four principal nonferrous metals, aluminum, copper, lead, and zinc, are given in figures 51 to 54. The curves show very much the same characteristics as those of steel production except that aluminum is probably much more on the upward trend than are the other metals. It is not at all out of line to think that more and more aluminum will enter into our lives as the years go by. There are a few technical developments in the background which will tend to accelerate this tendency even more than is indicated by the curve of figure 51. These will be discussed later.

It is not the function of this report to go into a detailed consideration of the probable utilization of metals in our future civilization, but it is nevertheless quite worth while to get a rough picture of the way the average consumption of steel is distributed. Table 26 shows relative distribution of the consumption of steel among the various uses in this country, from 1922 to 1935. Table 27 gives similar data for alloy steels. This latter type of steel is extremely important in our daily life, though the amount produced is very small, compared to the total production.

While the production of metals is under discussion, it is worth while to take note of the part which the United States plays in production and consumption of metals in the entire world. The world picture of metal production and consumption for pig iron and the major nonferrous metals is given in figures 55 to 59. The data plotted there are for the year 1932, which was a particularly low year in American metal production, so the relative amounts produced and consumed in the United States are now somewhat greater than those shown.

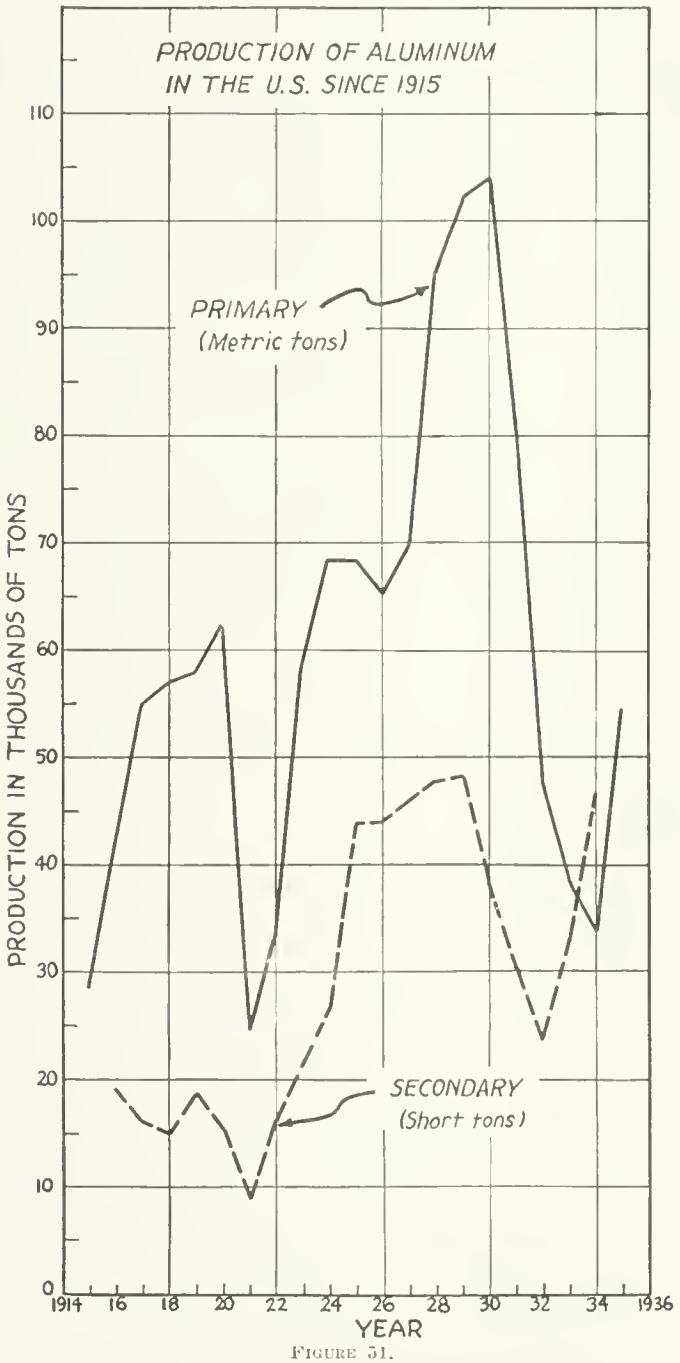

FIGURE 51.

Centuries ago the nonferrous metals were more important in the then-civilized world than was iron. But after iron and steel became abundant, the nonferrous metals lagged behind in relative production. The bulk of the weight of the metal produced in the world is now iron and steel, and will probably always remain so, but the use of nonferrous metals is distinctly increasing. For the 40 years ending with 1924, the ratio of pig-iron production to nonferrous-metal production was about 20 to 1, whereas, in the last 5 years the ratio has been about 14 to 1. This increasing importance of the nonferrous metals is shown by the rising curve in figure 60.

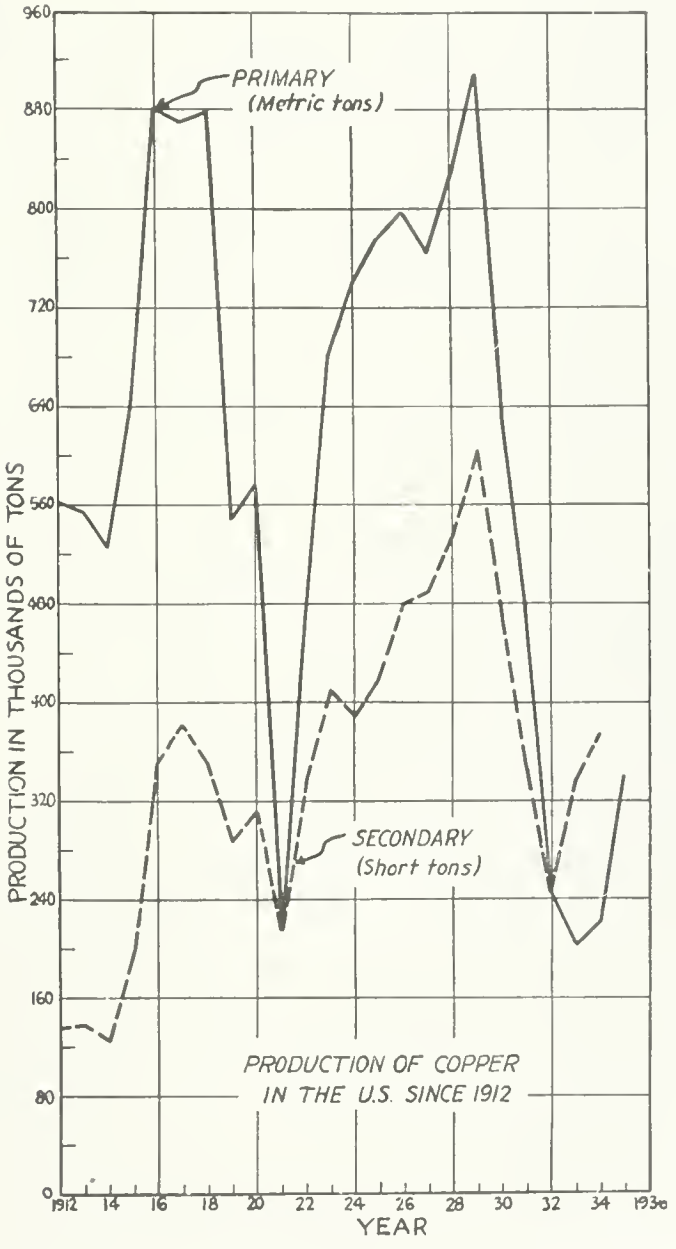

FIGURE 52.

TABLE 26.—*Consumption of steel—Ratios of main groups in percentages*[1]

Industry	1922	1923	1924	1925	1926	1927	1928	1929	1930	1931	1932	1933	1934	1935
Automotive	8.98	10.59	11.37	14.60	15.09	13.34	17.76	17.57	14.10	14.78	18.15	20.95	20.87	24.04
Buildings	11.84	13.53	14.44	15.26	13.10	14.89	15.22	14.70	17.80	16.80	16.38	12.18	12.70	13.01
Containers	4.16	3.68	4.96	4.20	5.24	5.21	4.56	4.67	5.77	7.90	10.79	12.25	8.68	9.39
Railroads	24.96	31.02	27.54	22.26	22.81	20.37	17.02	18.44	16.95	14.65	9.09	8.04	12.96	7.75
Agriculture	3.47	2.34	3.54	3.02	2.70	4.42	6.34	5.27	4.51	3.56	2.76	3.01	2.42	4.74
Machinery	2.83	2.63	3.69	2.69	2.65	2.79	3.48	3.81	3.80	3.37	3.39	3.63	3.65	4.37
Oil, gas, water	14.84	10.60	8.43	8.03	9.29	8.90	7.72	9.01	9.48	9.75	5.50	4.88	4.97	4.29
Exports	7.82	6.22	5.89	4.47	5.29	5.39	5.52	4.83	4.34	4.10	3.31	3.61	5.29	3.85
Jobbers					10.52	12.82	10.78	11.05	12.21	12.68	16.12	14.91	14.02	14.43
All other	22.10	19.39	20.14	25.47	13.31	11.87	11.60	10.65	11.04	12.41	14.51	16.54	14.44	14.22

[1] From Steel, Jan. 6, 1936, p. 206.

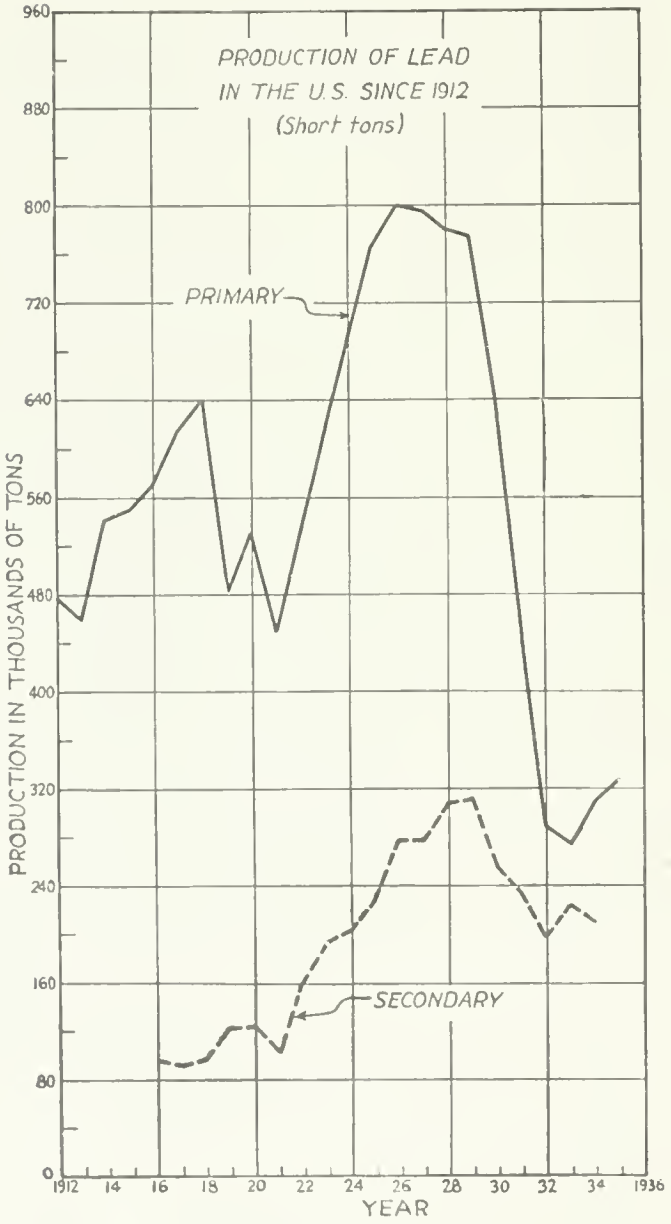

FIGURE 53.

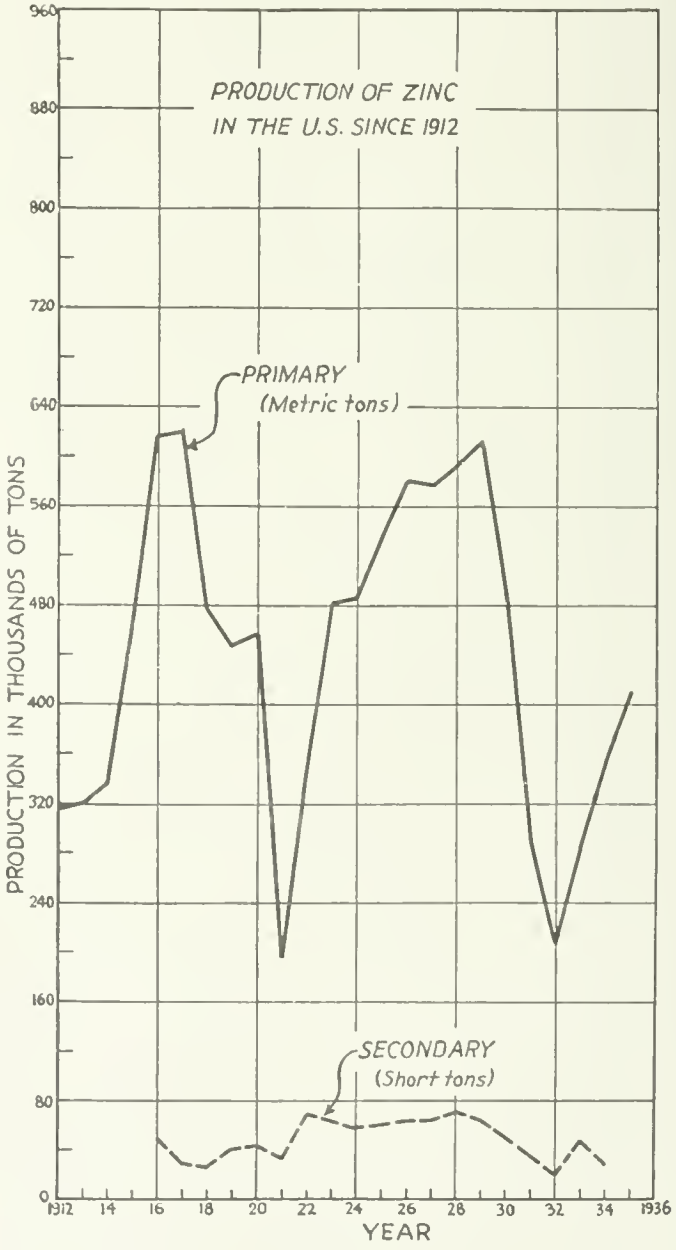

FIGURE 54.

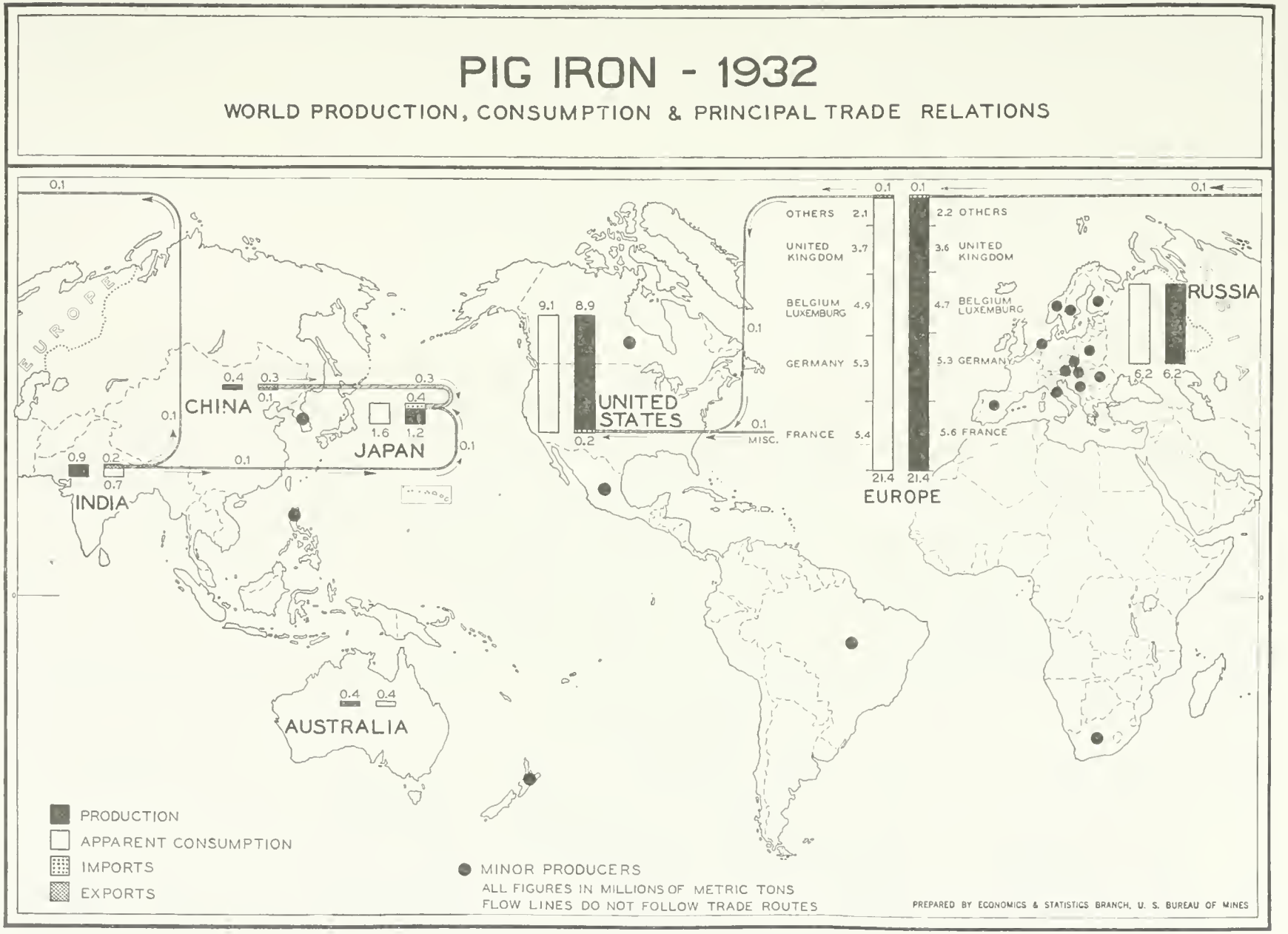
PIG IRON - 1932
WORLD PRODUCTION, CONSUMPTION & PRINCIPAL TRADE RELATIONS
EUROPE
CHINA
0.4
0.3
0.1
0.3
0.4
1.6
1.2
JAPAN
0.1
0.1
0.9
0.2
0.7
INDIA
0.4
0.4
AUSTRALIA
9.1
8.9
UNITED STATES
0.2
0.1
MISC.
0.1
OTHERS 2.1
UNITED KINGDOM 3.7
BELGIUM LUXEMBURG 4.9
GERMANY 5.3
FRANCE 5.4
21.4
EUROPE
2.2 OTHERS
3.6 UNITED KINGDOM
4.7 BELGIUM LUXEMBURG
5.3 GERMANY
5.6 FRANCE
21.4
6.2
6.2
RUSSIA
PRODUCTION
APPARENT CONSUMPTION
IMPORTS
EXPORTS
MINOR PRODUCERS
ALL FIGURES IN MILLIONS OF METRIC TONS
FLOW LINES DO NOT FOLLOW TRADE ROUTES
PREPARED BY ECONOMICS & STATISTICS BRANCH, U. S. BUREAU OF MINES

FIGURE 55.

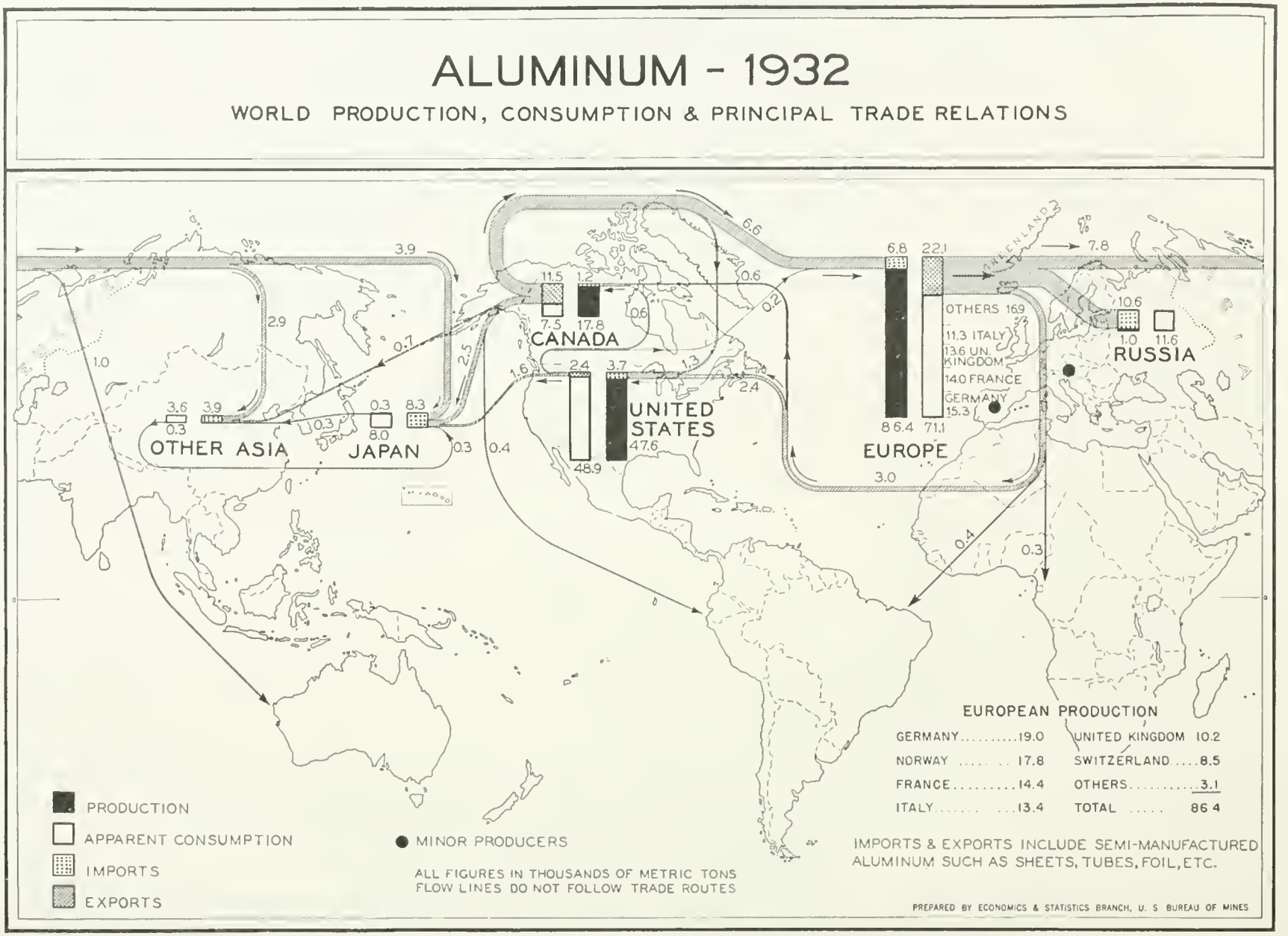
ALUMINUM - 1932
WORLD PRODUCTION, CONSUMPTION & PRINCIPAL TRADE RELATIONS
CANADA
UNITED STATES
EUROPE
RUSSIA
OTHER ASIA
JAPAN
GREENLAND
OTHERS 16.9
11.3 ITALY
13.6 UN. KINGDOM
14.0 FRANCE
GERMANY 15.3
EUROPEAN PRODUCTION
GERMANY.....19.0
NORWAY 17.8
FRANCE.....14.4
ITALY.....13.4
UNITED KINGDOM 10.2
SWITZERLAND.....8.5
OTHERS.....3.1
TOTAL 86.4
PRODUCTION
APPARENT CONSUMPTION
IMPORTS
EXPORTS
MINOR PRODUCERS
ALL FIGURES IN THOUSANDS OF METRIC TONS
FLOW LINES DO NOT FOLLOW TRADE ROUTES
IMPORTS & EXPORTS INCLUDE SEMI-MANUFACTURED ALUMINUM SUCH AS SHEETS, TUBES, FOIL, ETC.
PREPARED BY ECONOMICS & STATISTICS BRANCH, U. S. BUREAU OF MINES

FIGURE 56.

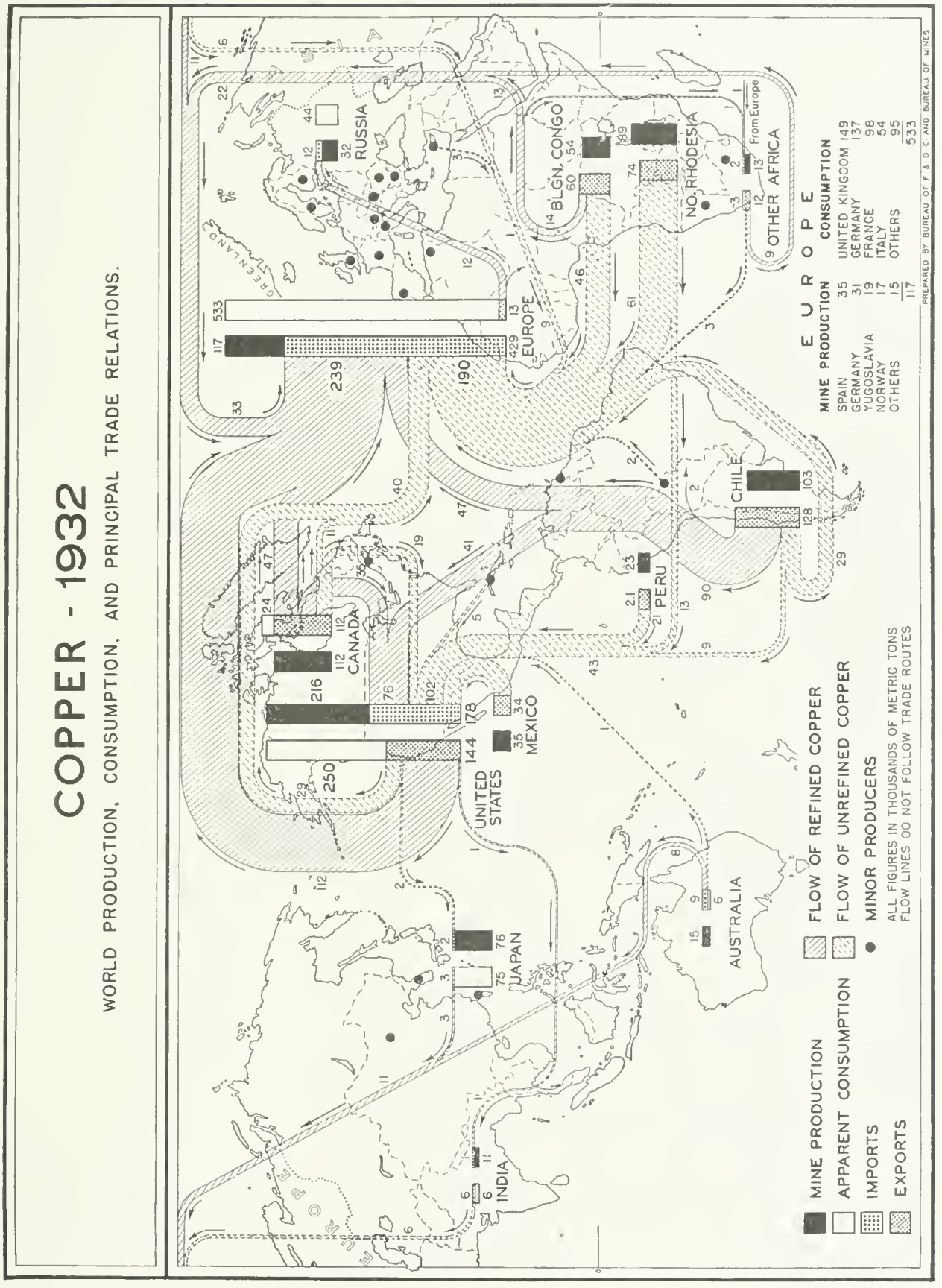
COPPER - 1932
WORLD PRODUCTION, CONSUMPTION, AND PRINCIPAL TRADE RELATIONS.
MINE PRODUCTION
APPARENT CONSUMPTION
IMPORTS
EXPORTS
FLOW OF REFINED COPPER
FLOW OF UNREFINED COPPER
MINOR PRODUCERS
ALL FIGURES IN THOUSANDS OF METRIC TONS
FLOW LINES DO NOT FOLLOW TRADE ROUTES
EUROPE
MINE PRODUCTION
SPAIN 35
GERMANY 31
YUGOSLAVIA 19
NORWAY 17
OTHERS 15
117
CONSUMPTION
UNITED KINGDOM 149
GERMANY 137
FRANCE 98
ITALY 54
OTHERS 95
533
PREPARED BY BUREAU OF F & D. C. AND BUREAU OF MINES
RUSSIA
BLGN. CONGO
NO. RHODESIA
OTHER AFRICA
From Europe
EUROPE
CANADA
UNITED STATES
MEXICO
PERU
CHILE
JAPAN
AUSTRALIA
INDIA
GREENLAND

FIGURE 57.

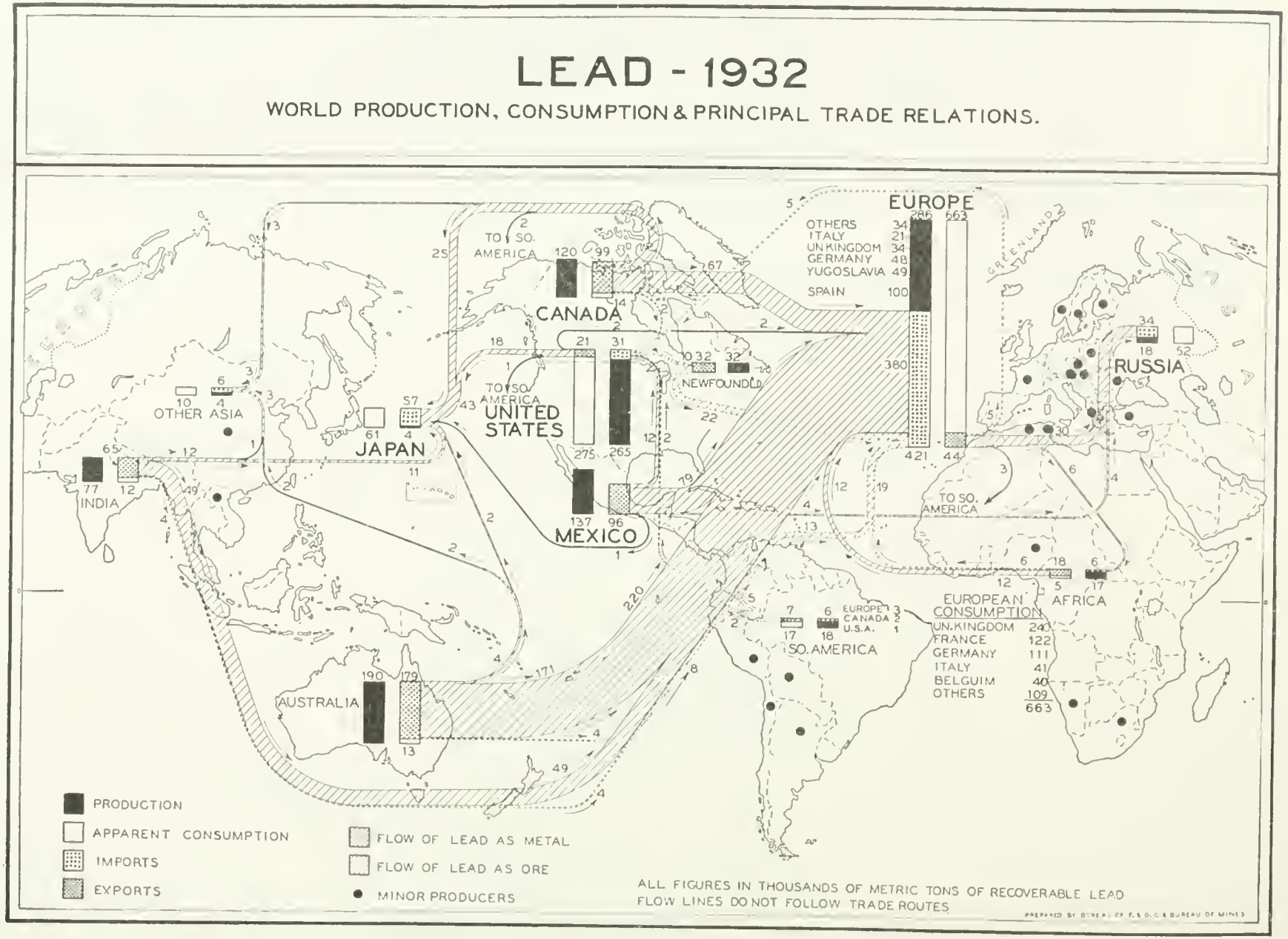
LEAD - 1932
WORLD PRODUCTION, CONSUMPTION & PRINCIPAL TRADE RELATIONS.
EUROPE
OTHERS 34
ITALY 21
UNKINGDOM 34
GERMANY 48
YUGOSLAVIA 49
SPAIN 100
286
663
421
44
380
CANADA
TO SO. AMERICA
120
99
14
UNITED STATES
TO SO. AMERICA
21
31
275
265
NEWFOUNDLD
10 32
32
JAPAN
61
57
4
OTHER ASIA
10
6
4
INDIA
77
65
12
MEXICO
137
96
RUSSIA
34
18
52
TO SO. AMERICA
AUSTRALIA
190
179
13
SO. AMERICA
7
17
6
18
EUROPE 3
CANADA 2
U.S.A. 1
AFRICA
6
18
5
17
EUROPEAN CONSUMPTION
UN. KINGDOM 240
FRANCE 122
GERMANY 111
ITALY 41
BELGUIM 40
OTHERS 109
663
GREENLAND
PRODUCTION
APPARENT CONSUMPTION
IMPORTS
EXPORTS
FLOW OF LEAD AS METAL
FLOW OF LEAD AS ORE
MINOR PRODUCERS
ALL FIGURES IN THOUSANDS OF METRIC TONS OF RECOVERABLE LEAD
FLOW LINES DO NOT FOLLOW TRADE ROUTES
PREPARED BY BUREAU OF F. & D. C. & BUREAU OF MINES

FIGURE 58.

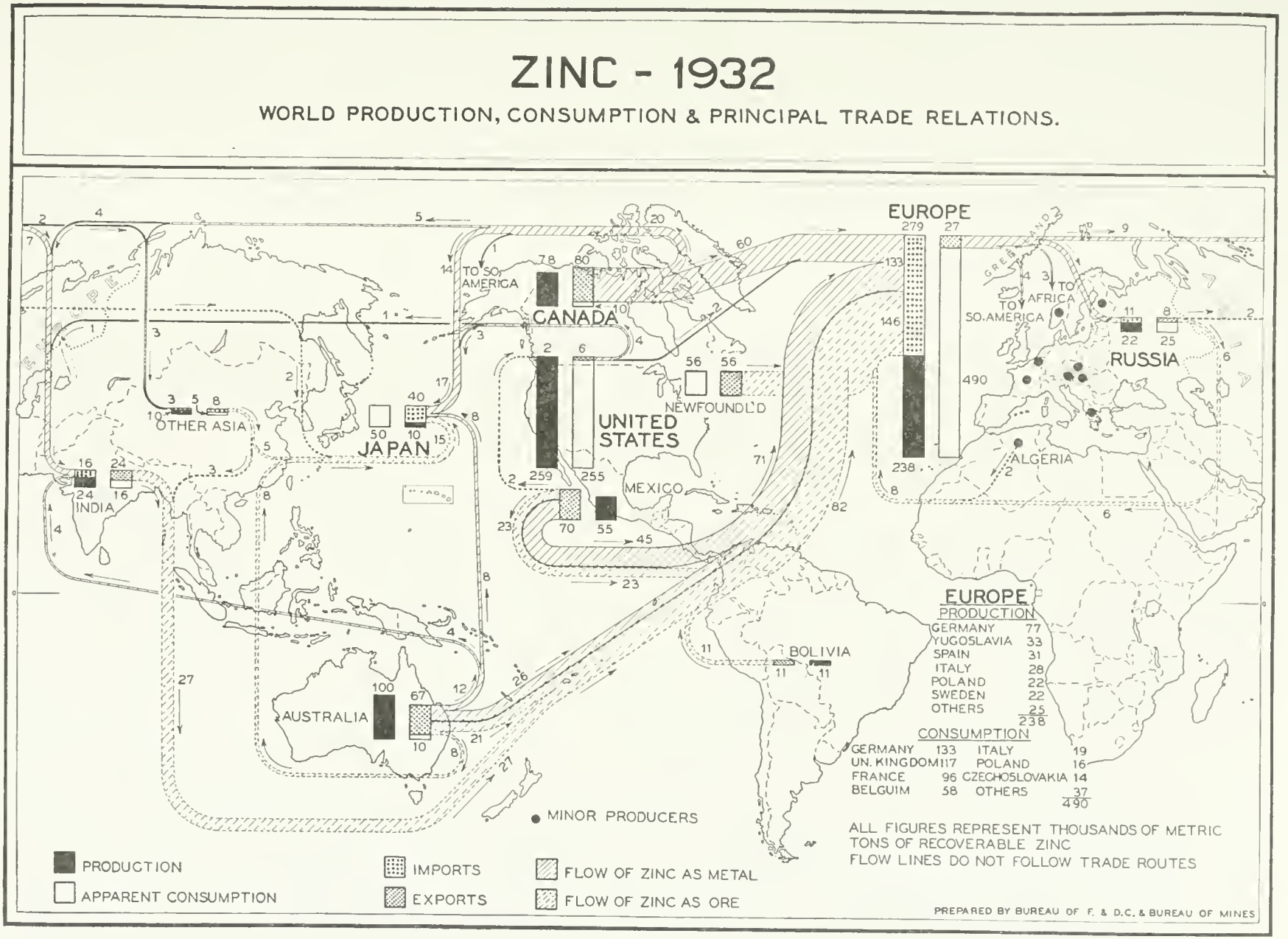
ZINC - 1932
WORLD PRODUCTION, CONSUMPTION & PRINCIPAL TRADE RELATIONS.
EUROPE
279
27
133
146
490
238
CANADA
78
80
TO SO. AMERICA
UNITED STATES
259
255
70
55
MEXICO
NEWFOUNDL'D
56
56
JAPAN
50
10
40
OTHER ASIA
INDIA
24
16
AUSTRALIA
100
67
10
BOLIVIA
11
11
RUSSIA
22
25
TO AFRICA
TO SO. AMERICA
ALGERIA
EUROPE
PRODUCTION
GERMANY 77
YUGOSLAVIA 33
SPAIN 31
ITALY 28
POLAND 22
SWEDEN 22
OTHERS 25
238
CONSUMPTION
GERMANY 133
UN. KINGDOM 117
FRANCE 96
BELGUIM 58
ITALY 19
POLAND 16
CZECHOSLOVAKIA 14
OTHERS 37
490
MINOR PRODUCERS
ALL FIGURES REPRESENT THOUSANDS OF METRIC TONS OF RECOVERABLE ZINC
FLOW LINES DO NOT FOLLOW TRADE ROUTES
PRODUCTION
APPARENT CONSUMPTION
IMPORTS
EXPORTS
FLOW OF ZINC AS METAL
FLOW OF ZINC AS ORE
PREPARED BY BUREAU OF F. & D.C. & BUREAU OF MINES

FIGURE 59.

TABLE 27.—*Alloy steel, consumption by groups, 1929–35—Percentages used by main groups*[1]

Industry	1929	1930	1931	1932	1933	1934	1935
Automotive	61.40	62.23	72.67	77.64	68.28	53.31	72.22
Machine tool	6.34	8.95	6.17	3.54	3.57	4.88	4.47
Oil industry	4.67	4.73	1.16	.82	1.96	1.52	1.77
Agriculture	4.05	5.94	3.30	1.69	2.07	2.42	2.87
Construction	3.72	1.00	1.09	.68	.66	1.55	.91
Export trade	1.38	1.16	.88	.43	.29	.58	.58
Railroads	1.62	2.66	1.83	1.92	.92	4.11	2.30
Shipbuilding	.22	.79	.52	.42	.47	1.21	.39
Miscellaneous	17.80	12.54	12.38	12.88	21.78	30.42	14.46

[1] From Steel, Jan. 6, 1936, p. 209.

Despite the fact that the nonferrous metals make up only about 7 percent of the total weight produced, the actual value is in a much larger proportion. The money value of the nonferrous metals in world production comfortably exceeds the money value of all the pig iron produced. In the United States the ratio is somewhat different for we are no longer the largest gold-producing country, but still our nonferrous metals are almost as valuable as the pig iron. This is shown in figure 61. As far as can be seen from this figure, there is no definite trend for the nonferrous metals to change their relative value over a period of years, but the two curves do give some idea of the relative importance of the two types of metals in our economic life.

Trends in the Cost of Metal

The trend of metal prices, relative to the general price level of commodities, during the last century has certainly been downward. If it had not been true, it would not have been possible to utilize the immense number of steel products which we find in the present era. In general, these decreasing prices have been a reflection of improved methods of production or lucky finds of rich ore deposits or both. As mineral deposits are depleted, the price naturally tends to rise, unless there are technological developments in processing which more than take care of the increased difficulty of recovery of the valuable part of the ore. So far, in this country, improved processes have very definitely kept ahead of whatever ore depletion there may have been, and that trend will probably continue for some time to come. There are some of these metals which we do not produce in any significant quantities because of poor qualities of ores. There are others, such as copper, of which we have an abundance of ore, but which is of a distinctly lower grade than that obtainable in other parts of the world, so American producers have difficulty in competing in the world market. However, even in these materials, the price tendency will probably be down, or at least constant, for some time to come unless there are artificial trade barriers which tend to keep the United States isolated from the rest of the world.

The price of pig iron and steel since 1910 is shown in figure 62. Since 1920 there has been a decided apparent reduction in price. The prices of the four principal nonferrous metals are shown in figure 63. However, the data should be interpreted in a somewhat different manner in order to show the price trends measured in terms of other commodities. Hence the data of figures 62 and 63 have been recomputed to give the "real" price of the various materials as adjusted by the price of individual commodities which are in use in this country. The basis of comparison is taken as the year 1926. The computations have been made on the basis of Dun's Weighted Index of Three Hundred Commodities and the Department of Labor, Weighted Index of 784 Commodities. The data so obtained then should really indicate the value of a ton of steel in terms of loaves of bread, pairs of shoes, or pounds of

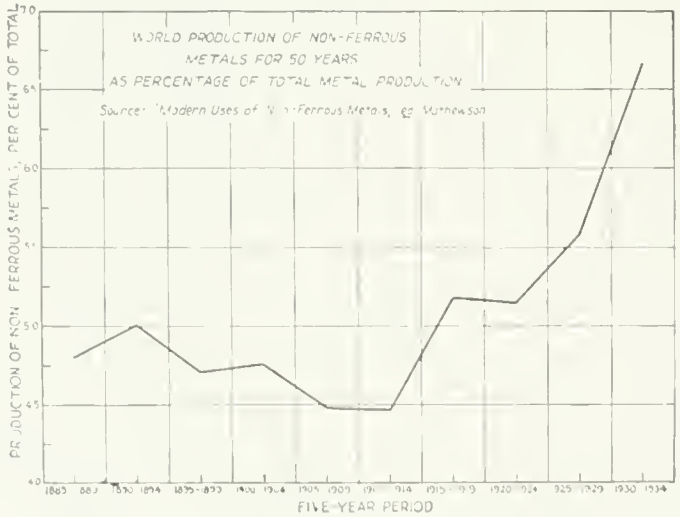
WORLD PRODUCTION OF NON-FERROUS METALS FOR 50 YEARS AS PERCENTAGE OF TOTAL METAL PRODUCTION
PRODUCTION OF NON-FERROUS METALS, PER CENT OF TOTAL
FIVE-YEAR PERIOD

FIGURE 60.

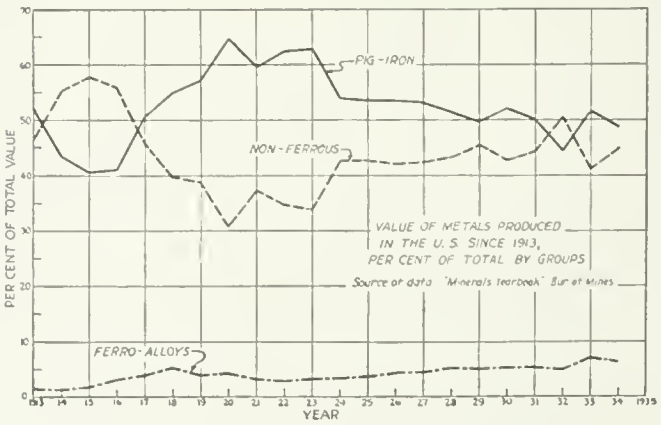
PIG-IRON
NON-FERROUS
VALUE OF METALS PRODUCED IN THE U.S. SINCE 1913, PER CENT OF TOTAL BY GROUPS
FERRO-ALLOYS
PER CENT OF TOTAL VALUE
YEAR

FIGURE 61.

sugar better than the simple listings of market data in the less fundamental item of the dollar.

The relative real price of pig iron and steel (1926=100) since 1913 is shown in figures 64 and 65. Since the period of the World War the trend has been downward though it has taken an upward turn since 1928. It is very likely that the real price level over the next decade or so will remain about constant. The relative real price of the principal nonferrous metals—aluminum, copper, lead, and zinc—are given in figures 66 to 69, inclusive. On the basis of both commodity indexes, the price of aluminum following the World War seems to have wavered around a constant figure. This is probably because of the fact that in the aluminum production no fundamental process changes have entered the picture for several decades. There is every indication that this condition may change very shortly and the aluminum price may be expected to come down. This will be discussed in a later section.

Copper, lead, and zinc show definite downward tendencies, though each of these curves has some decided hills and valleys.

From one point of view it might seem that the developments toward labor saving in the past two decades have not fulfilled their fundamental possibilities, because the prices of the metals have not made more drastic drops. There, of course, have been accusations to the effect that the metal industries, particularly iron and steel, have a much too heavy financial superstructure and hence the benefits of increased efficiency of production do not filter through to the consumer. It is very likely, however, that the truth of the matter is that the greater efficiency of production has given a slightly downward trend in the cost, but that greater

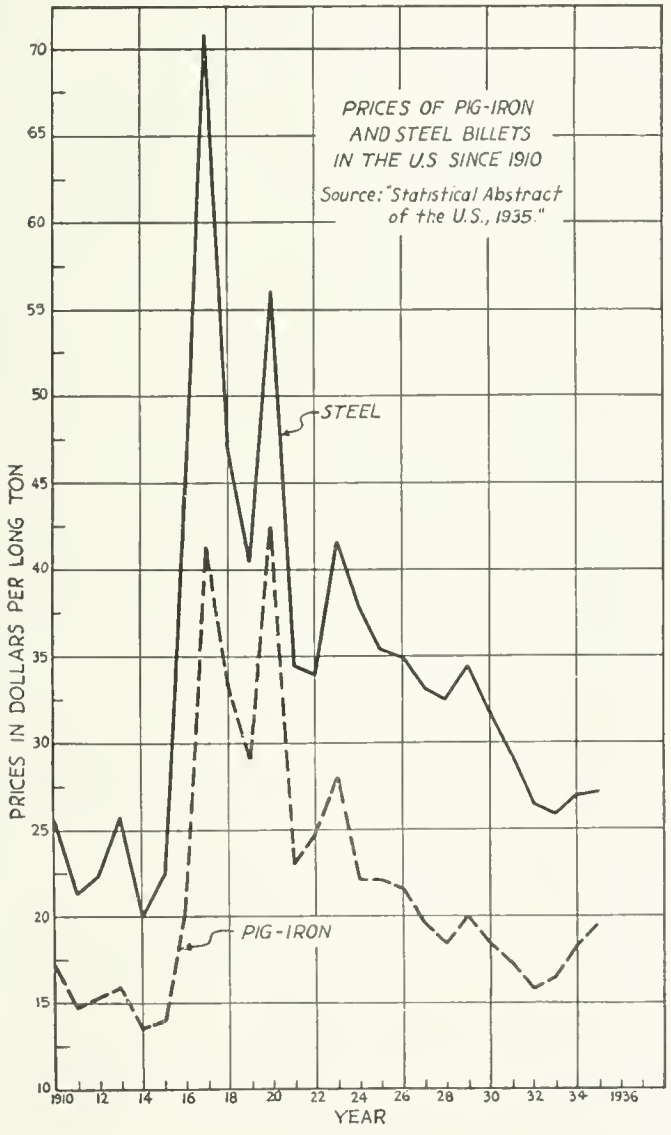

FIGURE 62.

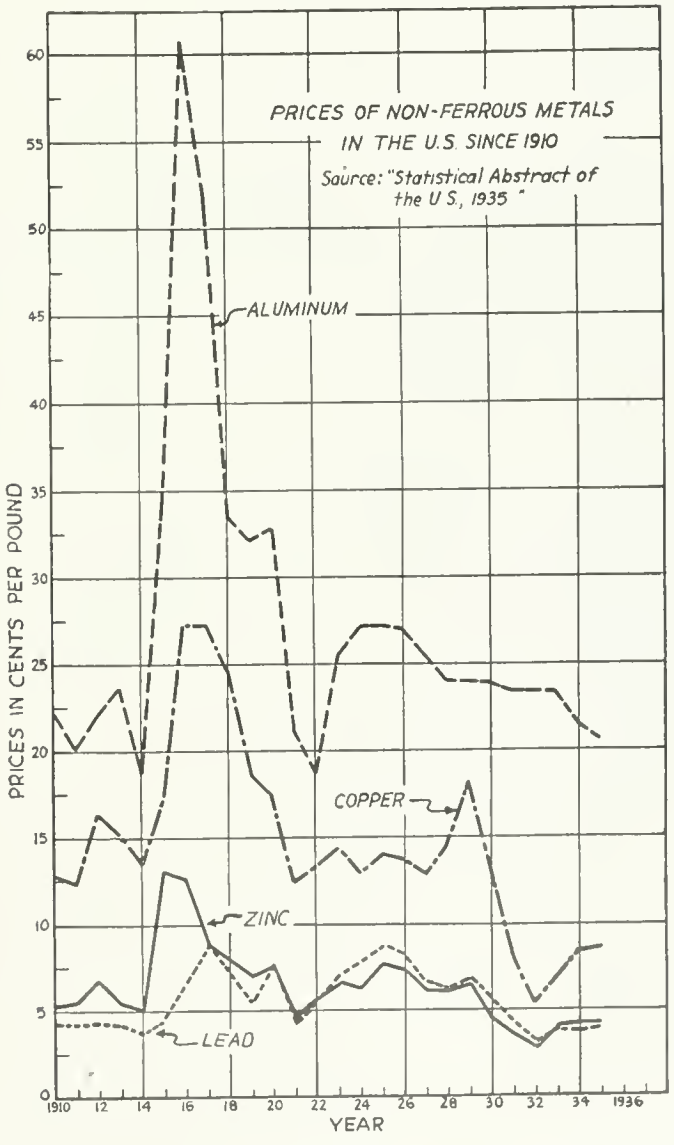

FIGURE 63.

social values have come about from the fact that the customer is now getting more for his money; that is, the quality of the products is distinctly and rapidly improving, both in chemical composition and in physical structure of the material. In the matter of estimating costs, the fact is significant that the amount of wages paid to labor has been greatly increased and the working conditions have been improved. This is particularly true in the iron and steel industry, for, in the first half of the 1920 decade, the steel worker was on the job 12 hours a day and often 7 days a week, whereas, despite the former grim opposition of steel executives, he is now, even at times of full employment, on an 8-hour day and works not more than 6 days per week. Thus, labor and the customer have both been greatly benefited. In considering the value received for the customer's dollar, these items must be kept in mind. These general tendencies in the real price of metals have been slightly downward only by virtue of the fact that the men who have been in the production end of the game have been successful either by fundamental research or, more often, by cumbersome processes of trial and error in handling the raw materials more efficiently. As more and more metals are taken from the crust of the earth, the quality of the ores and the ease with which they can be obtained will both decrease and, if the prices of metals are to continue downward or even to remain constant, it will be necessary to continue research and development at all times.

Any marked decrease in the price of metal products can certainly be expected to expand their market, but

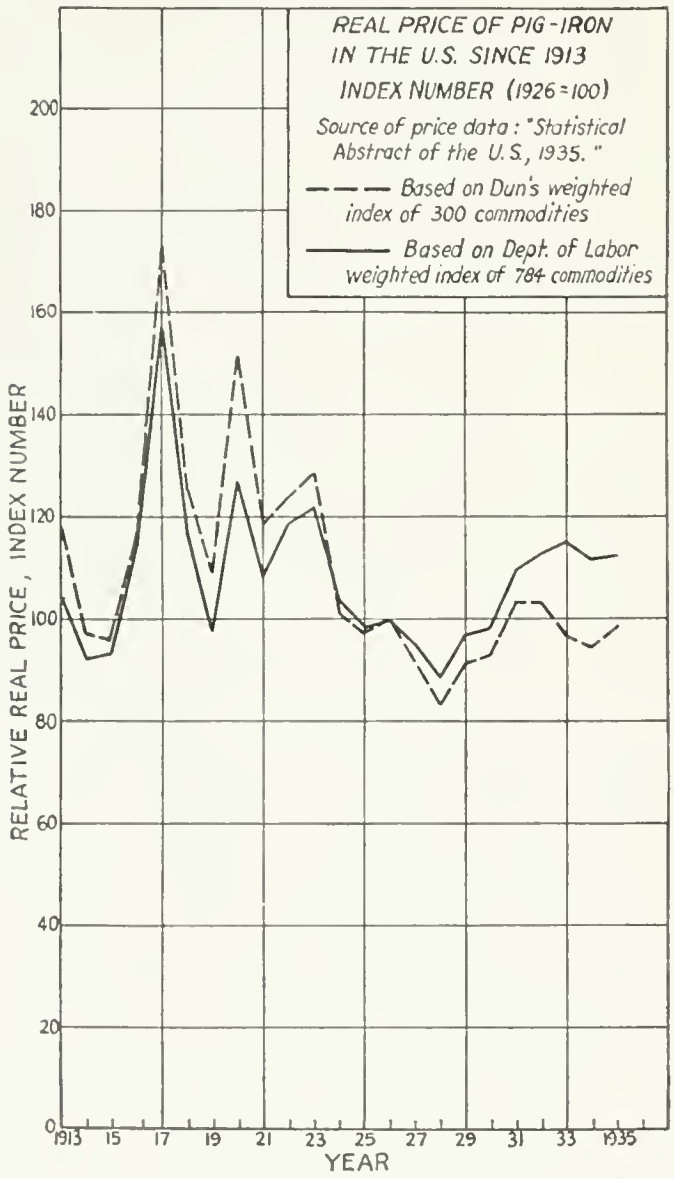

FIGURE 64.

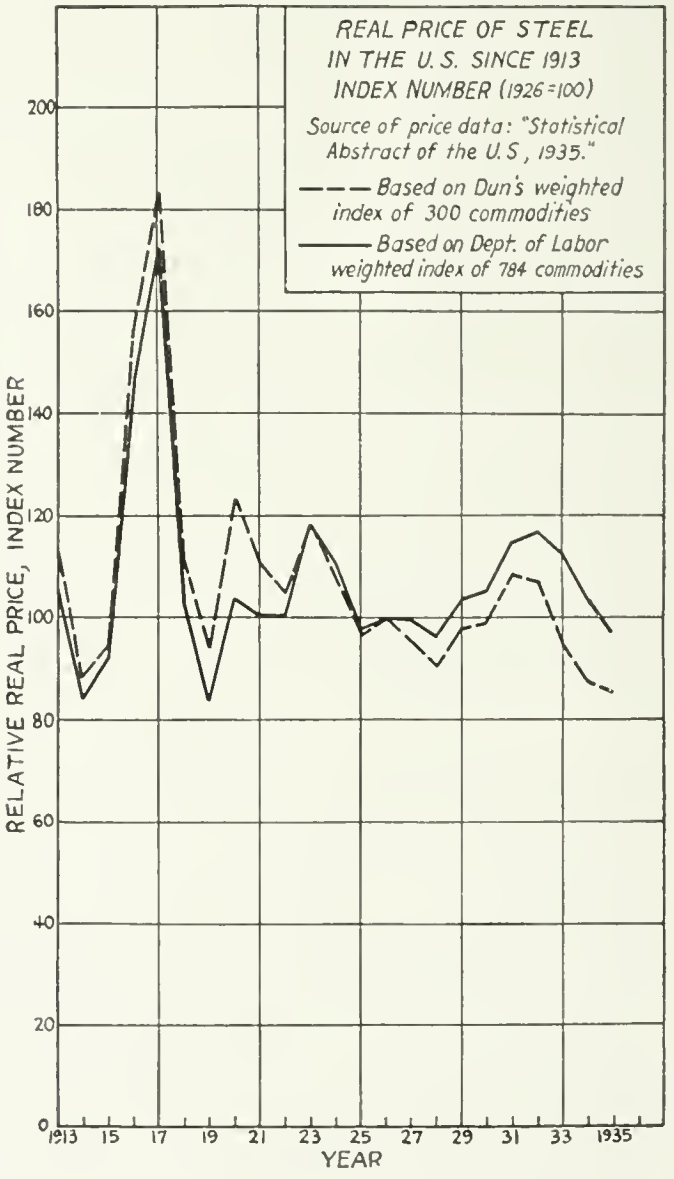

FIGURE 65.

it is quite likely that within the next generation such a decrease in price can be found not in the cost of the raw material, but in the cost of manufacturing of many articles and in their distribution. At the present time the cost of the raw material in the average finished article makes up only a very small proportion of the price paid by the consumer, so the part which metallurgists can play in the reduction of cost is probably not as great as the possible savings in the lines of advertising and marketing. Technical men are repeatedly distressed at seeing a 10-percent saving in production costs squandered many times over by a greatly inflated sales and advertising budget. However, no fundamental improvement in the situation can be expected as long as the American public actually prefers ballyhoo to getting its money's worth. Of course, this statement is not true for those types of heavy structures where the cost of the raw material is the major item.

Eventually the prices of all metals must rise as the quality of the available ores becomes poorer, for technological developments cannot always keep ahead of depleting resources. The price of some metals may start on the upgrade before many years pass, but it would be hazardous to predict which ones or how soon this tendency will be effective. It is quite certain that within the next generation the real price of some of our metals will rise enough to discourage increased use. This will mean that the material standard of living

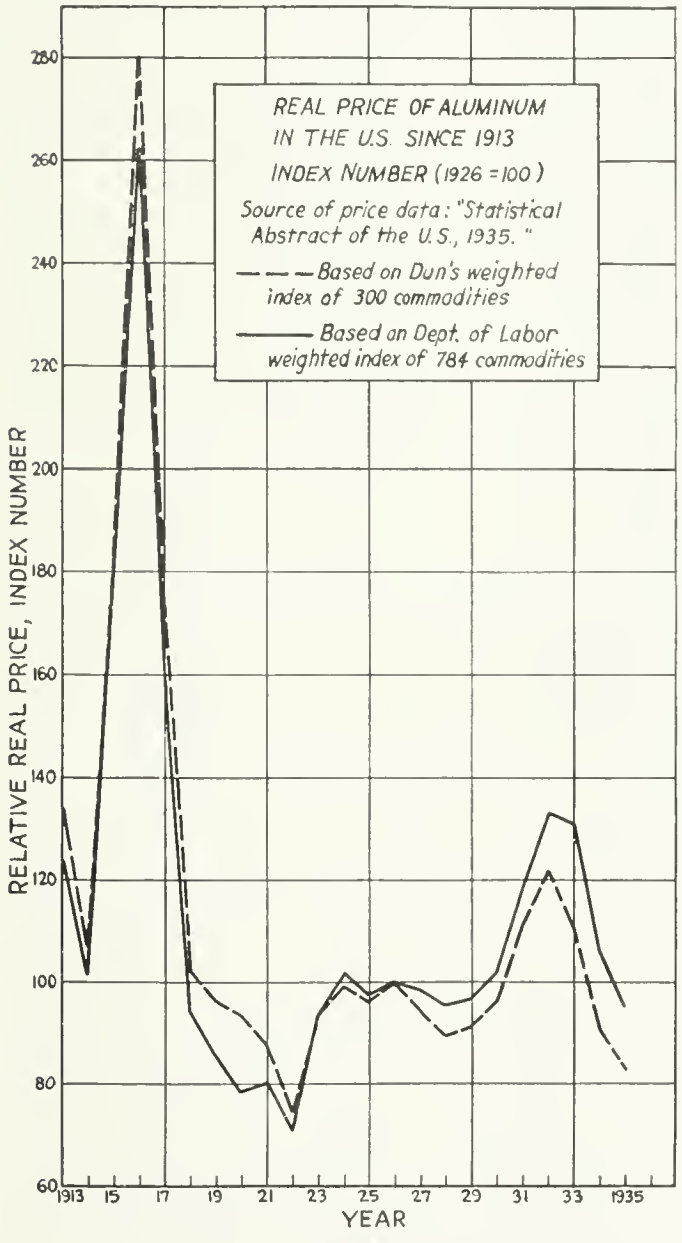

FIGURE 66.

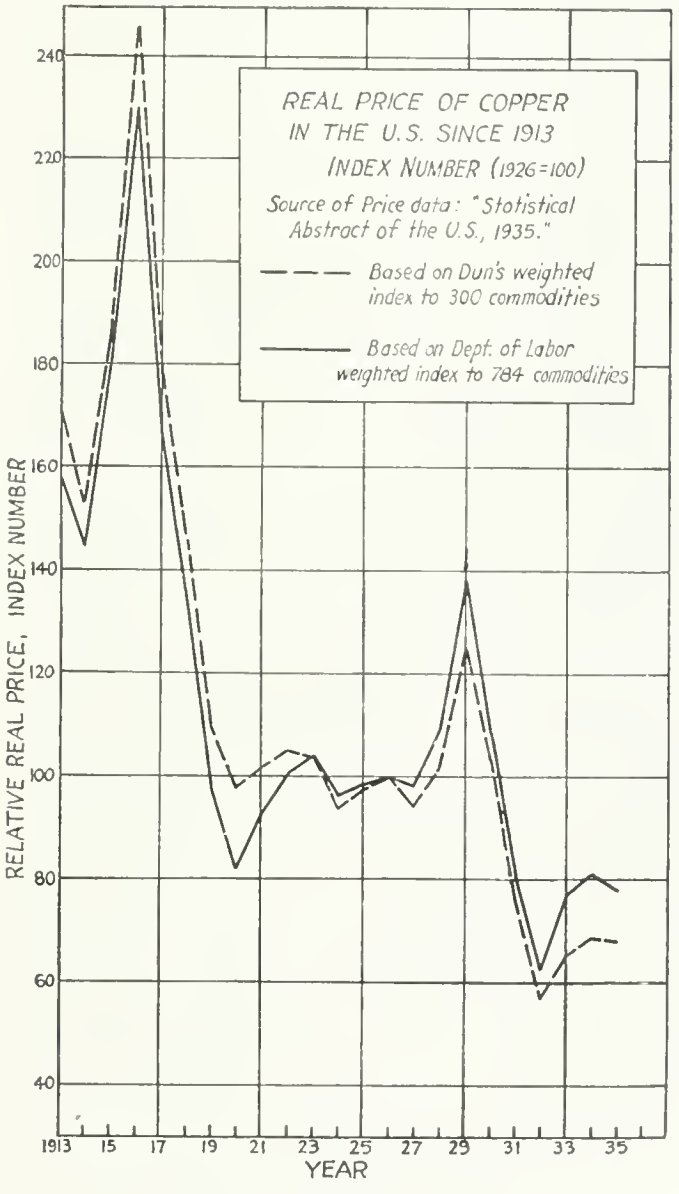

FIGURE 67.

will be on the downward trend unless human ingenuity can more than offset the depletion by increased efficiency of production in other fields. If we are to stand still, we must advance.

Corrosion

It is Nature's intention to keep the metals, with a few exceptions, in the corroded state. Man, with his infinite stubbornness, intends to keep this from happening. The item of corrosion plays an extremely significant role in modern metallurgy. About 15 to 20 percent of the iron produced is lost by rusting. Iron pipes under the ground usually resist corrosion better than those in the open air, yet the loss by underground corrosion in this country alone amounts to about a hundred million dollars per year. An appalling number of millions of dollars are spent every year in putting paints, lacquers, cements, and other unsatisfactory materials onto metals to keep them from disintegrating into a pile of rust. Although a great deal of progress has been made in research, the fundamental reasons for corrosion are not yet completely understood. Anyone with an airtight theory on the matter can find at least a dozen outstanding and able opponents at any scientific meeting. Fundamentally, of course, metals corrode because there is a strong affinity between metal and the oxygen or some other constituent of the air or whatever medium in which it happens to be immersed.

There is a tendency on the part of some people, particularly those who like to cast their eyes backward,

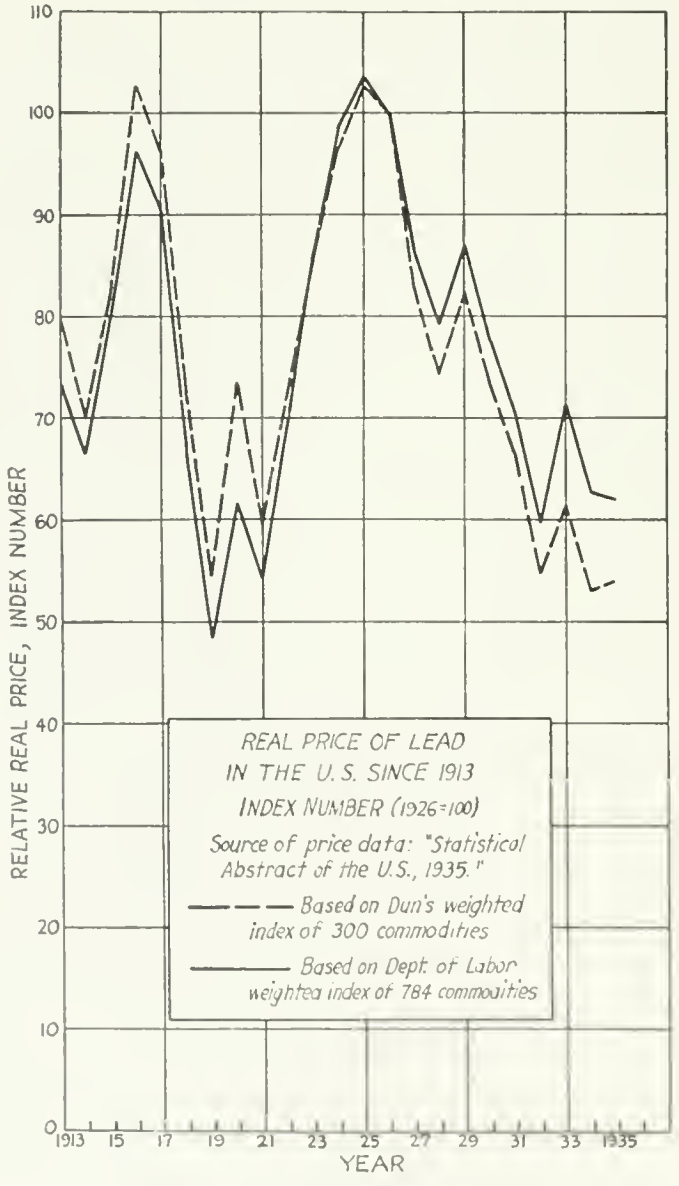

FIGURE 68.

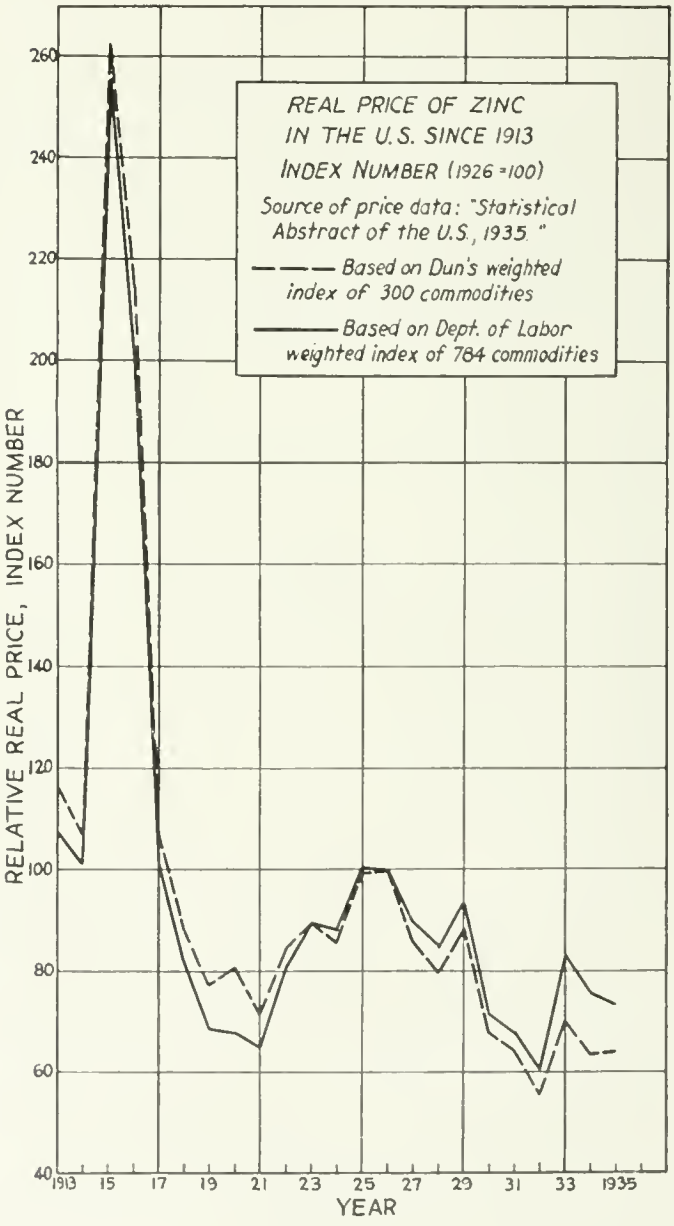

FIGURE 69.

to accuse the moderns of having lost some of the knowledge which the ancients had, despite the fact that we have searched and researched our physical world a thousandfold more thoroughly than did those supermen of 1,000 to 5,000 years ago. Metallurgists are repeatedly being reminded of the famous iron pillar at Kutub, near Delhi, India. Some unknown Hindu metalmonger, about 300 A. D., laboriously forged out the 6 tons of metal in this shaft. It still stands and is only slightly corroded. It is said that modern metallurgy cannot do as well. Actually, the iron in this pillar is no better than that which is produced in thousand-ton lots in this country all the time. It is a good grade of wrought iron, about 99.7 percent pure. Fortunately for its own reputation, it is situated in a locality where the atmospheric corrosion is not severe.

Some of the iron samples found in ancient Egypt were reputed to be practically corrosion proof, yet when these artifacts were brought to London and exposed to the English atmosphere, they soon passed out of the picture as a pile of rust. The ancient metallurgists have a reputation because they did their work in a dry climate. The truth of the matter is that the best iron of the ancients is about equal to the best pure iron of the moderns and we have numerous alloys which, for particular types of corrosion resistance, stand above the base metals of the ancients as much as our modern methods of transportation stand above the ancient Roman chariots. Whatever may be the cause of corrosion it is usually true that the purer the metal the more it resists corrosion. On the other hand, the addition of small quantities of another metal (copper to steel for instance) often gives a material that resists corrosion better than the pure metal. It seems that some of the ancient wrought irons were good because, while they were almost pure they did contain certain small amounts of copper which greatly increased their usefulness. It is a condemnation of our scientific procedure that only within recent years have we been able, in quantity production, to come back to the quality of metal of the ancients. However, we no longer need to look backward for our standards, for we can now outdo the ancient metallurgists on all counts.

Aluminum occupies a peculiar position in the corrosion picture, for it has a tremendous appetite for the oxygen of the air and hence should be expected to burn with extreme rapidity, whereas it actually is one of our best resisters of atmospheric corrosion. This is so because upon exposure to the air it immediately builds up a very thin but dense and tightly adhering coat of aluminum oxide which effectively prevents the free entrance of oxygen into the metal. In recent years it has been found that the aluminum which best resists corrosion is that which is 99.99 percent pure and so many of the light alloys which are used in airplane construction are covered with a thin layer of the purest aluminum in order to prevent corrosion. This layer becomes an integral part of the metal. Such material is called Alclad.

Magnesium is another metal, lighter than aluminum, which is extensively used in the light alloys. However, magnesium as a construction metal itself has so far been quite disappointing because of its wayward persistence in corroding either by itself or in its alloys. If the generalization that the purest metals do not corrode readily is true, then strictly pure magnesium should be very much better than that which is not quite pure. Until recently developments along the line of the production of noncorroding magnesium have been quite discouraging. Experimental work has been done with magnesium metal which has been redistilled in a vacuum out of the presence of oxygen. There are indications that this metal may become one of the strictly corrosion resistant materials. It is also significant to note that the most corrosion resistant aluminum alloy is that which contains 10 percent of magnesium.

Recent years have seen the advent of the so-called "stainless steels" in the metal industries. The first man to invent a stainless metal that could be used for tools was Haynes, of early automobile fame, but his material was not a steel. It was an alloy of cobalt, chromium, and tungsten. It is very tough, retains its properties at red heat and is used as a cutting tool material. It does not corrode, but it is very expensive. This was followed by Brearly's making of a satisfactory stainless steel in England. The most successful material which was relatively inexpensive (though it still costs 20 to 30 cents per pound) and which was practically noncorrosive in the atmosphere, was the so-called "18 and 8 stainless steel" invented in Germany and covered by the Strauss patents. This material has had a truly phenomenal development in this country as well as abroad. It has been the subject of much licensing and many litigations. There are several hundred patents involving modifications of this original Krupp development. The basic patents expire within the next year and the cessation of royalties may tend to bring the price down slightly. Probably the greatest mass exhibition of stainless steel in this country is on the outside of the Chrysler Building in New York City. It is standing up very well under the trying atmosphere in which it is immersed. Even this material has its drawbacks. It offers but very little opposition to the corrosive action of salt water. The United States Navy had some irritating experiences with the corrosion of stainless steel used as gasoline tanks in which salt water displaced the fuel.

It is quite evident that even in the "stainless" material there is still much to be done in the development of corrosion resistance. It has been found that the metal is most susceptible to corrosion in the neighborhood of a weld but that this condition is very much improved by the addition of small amounts of titanium, a metal which apparently has few other uses. A more recent development, and one which has been quite successful, is the addition of columbium; but columbium, unfortunately, is quite expensive.

Another metal which is outstanding in the corrosion-resistant field is Monel. It is an alloy of copper and nickel and so is inherently relatively expensive. However, it lies in a price range which permits it to be used for kitchen and hospital equipment and in a number of chemical manufacturing processes. It retains its appearance in the atmosphere and was early shown to be resistant to sea water. It was introduced some 30 years ago as a rustless material as strong as steel. An experimental yacht, the *Seacali*, was constructed in 1915, at a cost of a half million dollars, from Monel metal sheet fastened on a steel frame with steel rivets. It was to be practically indestructible. Within 3 months after its launching, the structure was so corroded that the yacht had to be scrapped. It was simply another example of the fact that a little knowledge is a dangerous thing, for the combination of iron and Monel metal made ideal voltaic cells and the corrosion of the steel rivets and frame proceeded at a very rapid rate. If the entire structure had been of Monel, it is very likely that the vessel would have been practically indestructible, for under proper conditions it is a highly satisfactory corrosion-resistant metal. The unfortunate incident lead to a great deal of research on the part of the International Nickel Co. and it may very well be said the use of Monel metal was greatly advanced by the many developments which were made because of the results of this rather expensive experiment. Aluminum alloys are also quite susceptible to corrosion when in contact with dissimilar metals.

In the field of corrosion-resistant steels of the ordinary variety, the very low carbon Armco iron, which is made in a steel furnace but which in many respects is the equivalent of the old-time wrought iron, has now been on the market for a number of years. This material is used a great deal for underground service. Another type of corrosion-resistant inexpensive steel has been pushed particularly by the United States Steel Corporation, namely, copper-bearing steels. Though in the early years it was thought that copper was deleterious to steel, it has now been shown that this is not true, for a few tenths of a percent of copper distinctly improves the resistance to atmospheric corrosion, without very much additional cost. The introduction of copper into the ordinary grade of steel has marked a distinct advance in the battle against corrosion.

The materials which have just been discussed are examples of the types of metals which are within themselves corrosion resistant though, of course, none of them are absolutely corrosion proof. The one time-honored method of resisting corrosion is to coat an inexpensive material with a very thin layer of something which will resist corrosion, at least for a time. The almost microscopic layer of tin in food cans is an example, and the layer of zinc on galvanized iron is another. It would be rather hard to picture what our life would be without galvanized iron or tin plate. These materials are put on by the process of dipping, that is, the clean base metal is dipped into a bath of the molten tin or zinc. Another method of coating is found in the "clad" materials, such as "Alclad", where pure aluminum is rolled onto an aluminum alloy; or "stainless" or nickel-clad, where these resistant materials are rolled onto a steel or iron base.

Another method of putting on protective metal coatings is that of electroplating. Silver, gold, and nickel have long been plated on articles in this way. Within the last decade chromium platings have come into wide use. Chromium plate, however, is not a very good protective plate for the iron metal which may be underneath, so it must be backed by copper and nickel plates. Very recently it has been found that a superior coating of zinc can be put on by a process of electrolysis, and it may be that the dipping process for the galvanizing of iron will eventually be displaced by the process of electroplating zinc. Tungsten plating is beginning to come in as a serious competitor of chromium plating.

Another successful attempt at resisting corrosion has been found in the so-called "anodic coatings." In the airplane industry, such coats are acquired by hanging the object to be protected at the anode of an electric circuit in a bath containing chromic acid or sulphuric acid. This builds up a strongly adhering coating of the oxide of the material which protects the metal. Modification of this process consists of putting phosphate or other salts into the solution. Various metals are being anodized in this way more or less satisfactorily.

One side light on this is the recent development in producing any desired color in these anodic coatings on aluminum. This, then, brings into the field not only the corrosion resistance, but also the item of decoration and hence begins to enlarge the possibility of the method by manyfold.

It is quite certain that these newer items in the coating of metal are not only going to make many things possible which were not possible heretofore, but is also going to make many corrosion-resisting metals much less expensive and thus open up new markets for

metals. These more or less successful attempts to bring corrosion under control are going to have a decided effect upon the picture of metal production in the future for the more metal that is saved from the destructive forces of the elements, the less new metal will have to be produced. Paradoxically, the metal producers who have done most of the research upon corrosion resistance will probably eventually suffer a contraction of their market simply because of the efficiency of their research. On the other hand, competition among producers is very keen, and if one is to stay in business, he must advance in order to give better and better products to consumers. It would seem, then, that the metal producer will eventually be caught upon both horns of his dilemma; and while this possible contracting market, because of improving corrosion resistance, is not yet a major consideration, it is something which must be thought about in the future. This line of discussion naturally now reduces itself to the matter of the recirculation of metals officially known as secondary metal products or, more commonly, as "scrap."

The Recovery of Scrap Metal

Since this country was saved from the Stone Age of the Indian to be plunged into the iron age of the white man, we have produced over 1 billion tons of metallic iron in one form or another. Approximately 15 to 20 percent of this primary production has been irrecoverably lost by rusting, according to the best authorities. On the average, about 35 percent of the total primary production is irrecoverably lost either by rusting, burying in the ground, or putting into objects from which it is not profitable to recover the metal. This leads to the estimate that there are at the present time in this country about 700 million tons of iron and steel which will eventually find its way back to the scrap pile to be remelted and used again. This is an immense mine of material which must be reckoned with if we are to consider metal production in future years. At the present time about 65 percent of all the iron and steel which is produced eventually finds its way back to the steel mills as the material for refabrication. About 25 percent comes back to the steel mill in a short time and most of the remaining 40 percent has returned within 30 years.

It should be pointed out that in the past, most of the production has gone to fill the reservoir which is represented by new structures. In other words, we have been expanding the amount of steel equipment and structures in this country for the past three centuries. We might conceivably come to the point, because of decreasing demand and a static population, where there would no longer be a demand for building an ever increasingly large number of new structures. Then the market for primary iron and steel might only be that required to replace the 35 percent which has been lost. Eventually the market for metals may only be that of replacement. How soon this day will come depends upon the standard of living as measured by the use of metals which will be available for the average American. It must also be remembered that this figure of 15 to 20 percent lost by rust is being rapidly decreased, so that the amount of primary metal required for replacement is going to become less and less. The possibilities of new utilization for these metals will be considered in a later section, but briefly it can be stated that there is but little prospect of a boom in the production of iron and steel. Dependable figures for the rate of recirculation of scrap in the United States at the present time are difficult to obtain, for there is no really effective clearing house for scrap figures. The picture is also complicated by the fact that in all steel mills there is the use of a great deal of what might be called "intramural" scrap. This intramural scrap is the pipe ends of ingots, and the cut-off ends of billets, the spattered metal, etc., which is collected around the mill and then recirculated through the steel-making furnaces. This, on the average, has been staying quite constant at about 25 percent of the total production. The outside scrap, that is, that which has been in use and which is purchased from a scrap dealer and then sent to the mill, amounted to about 10 percent of the total steel produced in the early 1920's, and had steadily risen to about 25 percent in the early 1930's. This is a gradual trend which does not appear to be affected by change in business conditions and hence is apparently quite significant. At the present time, then, about half of the charge going into the average steel furnace is scrap metal and about half of this is what has recirculated from the outside. This figure may be expected to increase in the future and thus to decrease the amount of new metal required. Scrap iron and steel is also being charged into some blast furnaces.

If we become engaged in a process which is largely recirculation, there will be serious technical difficulties involved. Metallic elements which are put into steel are not removable by any ordinary steel-making process, hence most of the copper, nickel, tin, tungsten, chromium, etc., which has been put into a batch of steel eventually comes back to the steel mill in the metal whether the producer likes it or not. Thus the amount of nonferrous metals in iron and steel is gradually building up. Some are desirable and some are very definitely not wanted. This involves a number of troublesome details in the matter of classification of scrap, analysis of materials, and constant care in adapting the metals to their needs. The more scrap used the more vigilance is required on the part of the steel makers. This is an item of increasing technical

importance which the producer has to take into account.

The figures of scrap production in the nonferrous field are much more authentic than those in the ferrous field. The production of scrap for the four principal nonferrous metals is shown in figure 70 as the percentage of the total. Whereas the amount of recirculation in the steel industry is now in the order of 25 percent, it will be noticed that for copper and aluminum the recirculation is well over 50 percent, that is, there is more secondary metal being used than primary. This is a tendency which has been particularly distressing to the copper people and was an item which some of the major copper producers apparently forgot in their attempt to increase production at the same time that they raised prices a few years ago. The rise in price brought scrap copper into circulation from every nook and cranny of the country and tended to act as a balance wheel upon the amount of primary metal which could be produced. Lead is a metal which is approximating equality between a primary and a secondary production. A great deal of this, of course, is accounted for by the "turn-in" of automobile storage batteries. The percentage of zinc which appears as secondary metal is remarkably low, probably due to the fact that a great deal of it is used in galvanizing steel and hence is not recovered.

As uses of a metal expand, the proportional production of scrap drops because it is necessary to have a larger primary production to take care of the demand so that as business cycles go up and down, relative scrap production tends to do just the opposite. But there is no doubt that for copper, lead, and aluminum, the general trend is for a larger and larger percentage to be recirculated. This tendency is being reflected in new designs which permit easy recovery of scrap. This is what would certainly be expected from relatively expensive materials which do not corrode easily.

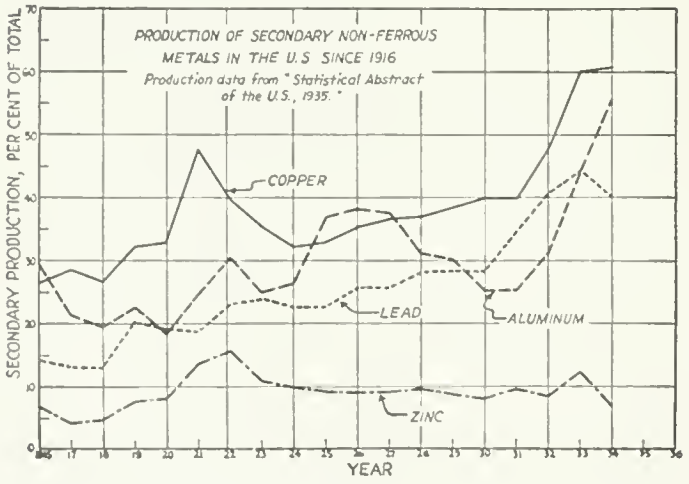

FIGURE 70.

Most Significant Developments In Metallurgy in Past Few Years

Ordinarily the consumer does not see the result of scientific or technical advances until many years after the original discovery or invention, for it always takes a great deal of time and effort to convert an idea into a laboratory success and then into a technical advance. Moreover, there are always various types of inertia to be overcome all along the line; sometimes financial inertia because of new investments required, then perhaps the inertia of the executives' prejudices, and finally, the very slow moving mass of the operator's and then the consumer's mind must be changed. A great many of the advances in an industry are due, not so much to a new discovery or an invention, as to the greater adaptation of facts or equipment already long in existence. The bulk of research in recent years as well as the dispensation of scientific information has come from the metal consumers rather than the producers. American metal producers, until recently, have been particularly narrow in their policies of research and development.

In the iron and steel industry there have been a great many strides due primarily to economic pressure since the relatively carefree days which ended rather abruptly with the 1920's. Now they actually read and record temperatures of heats of molten steel. That was nothing but a piece of academic foolishness a few years ago. In a word, the steel industry is becoming modernized. It is estimated that in 1935, 140 million dollars were spent on what might roughly be called modernization, and in 1936 some 200 millions will probably be spent for the same purpose. Stress is being placed upon efficiency of operation and quality and adaptability of the product. Steel is being produced in small lots to exact specifications to fit individual needs. The steel industry can now supply some 500 different products in as many as 100,000 different grades, shapes, and sizes. Part of this is due to what might be called "customer pressure", rather than from any desire from the inside to improve. This is particularly true in the field of sheet metal. In 1929 less than 25 percent of the production was in the form of steel sheets. That figure rose to 43 percent in 1935. Single-piece automobile tops, and pressed-steel bathtubs are partially responsible. This increased production of sheet metal has resulted in the construction of the automatic continuous strip mills mentioned in a previous section. There are now 21 such mills. In 1926, sheet steel cost $83 per ton, $30 of which were for labor. In 1935, it cost $53 per ton, $21 of which were for labor.

Another very important step forward, initiated by American steel manufacturers in the last half decade,

has been through the control of grain size of finished steel, by proper temperature and work control and the addition of certain metals, such as aluminum. This has permitted much closer control of all steel properties. It has been found that ordinary plain carbon steels can now have strengths only found in the better alloy steels a few years ago. In other words, one of the functions of alloying elements in previous years was to cover up sloppy steel-making practice. The carefully controlled plain carbon steels and the new "low alloy" steels are now so satisfactory and uniform in properties that they are displacing many of the more expensive high-alloy steels, particularly in the automobile business. These new steels average so much stronger than the old carbon steels that structures, freight cars, and truck bodies can be made 25 to 40 percent lighter than formerly. Some of the new lightweight streamlined trains are made of these alloys. With competition and consumer pressure behind them, the more forward-looking steel makers have been very much on the job. Adversity has a few highly significant uses.

On the other hand, pendulums usually swing too far. Unquestionably, consumer pressure has resulted in a nonsensically large number of products. The customer has found that he can demand a material made to almost any type of specifications and get it. This is truly a revolutionary change from the condition not very many years ago. It is very distressing to the metal producer, for it means a great deal of trouble, much greater carefulness of operation, and more expense, yet the price of the finished product has kept on the downward trend. We seem to have entered a permanent era of the consumer's market; that is, one where the consumer of the products dictates what shall be produced. To one not in the metal-producing business this is unquestionably a healthy trend, for after all the consumer is the most important individual in the entire industrial scheme.

As it is now, a large part of the metal production is in custom-made lots produced to individual specifications. This, of course, is an enemy of standardization and also of low prices. Many of the specifications of chemical analyses and physical properties are absolutely unnecessary and fill no purpose except to emphasize a particular customer's prejudices or sense of superiority. Undoubtedly, the field of the steel industry could be just as well covered with 100 products as it is now with the 500 products mentioned above. The author knows of one brass company which stands ready to produce any one of two hundred different alloys, not because it wants to, but because a customer may demand them. It is very likely that the entire field of physical and chemical properties inherent in that number of alloys, could be covered with one-fourth as many. In the entire field of metals there are great possibilities of deriving benefit for both the producer and the consumer by standardization of the products and the elimination of any unnecessary specifications. Considered in the light of the statement of the immense number of possible alloys made previously, this would seem to be paradoxical. However, if the metal produced is sufficiently versatile, it is not necessary to have nearly all possible variations commercially available.

Some medium of compilation of accurate and authentic information on the physical and chemical properties of the many types of metal alloys would undoubtedly be beneficial. Before any such compilation of information or standard of production can be effective it will be necessary to be certain that it is authentic and then to educate the metal consumers on the dependable range of chemical and physical properties of the various standard materials.

Unquestionably, as research advances, there will be many new products coming into the market and some of them will be superior to any now put out and will probably replace old materials. Some of them will effect a lowering of costs, others undoubtedly will be developed in the interest of corrosion resistance. Items of ductility and weldability also enter the picture at many points.

When one speaks of possible new products he always finds someone who inquires as to when modern man is going to learn to harden copper as the ancients did. This idea that the ancients knew something about copper that is not known at present is the purest bunkum and has often been used to promote fraudulent stock selling schemes. The process for the hardening of copper simply consists in making a copper alloy which is inherently hard or can be made so by heat-treating or work-hardening. We have a variety of such copper alloys, some of higher quality than can be found in any ancient artifacts. One of the most striking materials is beryllium copper. Beryllium is very expensive, but it is finding quite a little use when 0.1 percent or so is alloyed with copper to make corrosion-resistant tools or springs, as well as for hard, nonsparking tools. The material is very tough and has a hardness equal to that of the best steels. If the price of beryllium can be materially reduced below its present level of $25 per pound, this unusual copper alloy will find a wider use.

Many of the outstanding developments of the past have been due to the adoption of electrical processes to metallurgy. For instance, in the electrorefining of copper, America leads the way with her rather stubborn and low-grade western copper ores. Not only was a better grade of copper produced more cheaply than was possible with the old complex pyrometal-

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lurgical process, but the residual gold and silver were turned into profits. At the present time a multitude of metals, notably copper, silver, gold, nickel, lead, bismuth, iron, antimony, and zinc are electrolytically refined. Others are reduced from their ores by electrolysis in a bath of fused electrolytes. The principal materials produced electrolytically or subjected to electrolytic refining are aluminum, beryllium, calcium, cerium, lithium, magnesium, and sodium. A great deal of electric energy is also used simply as a source of heat in the metallurgical industry. Practically 95 percent of the brass is now produced in electric furnaces of various types and an ever-increasing percentage of the alloy steels is being produced in electric equipment, not to mention the fact that a great deal of the ferro-alloys which are used in making up finished alloy steels are produced in electric furnaces.

The most abundant metal in the earth's surface (if silicon is considered a nonmetal) is aluminum. It is estimated that over 8 percent of the outer 10-mile shell of the earth is aluminum, whereas iron can only account for 5 percent. Another light metal which is beginning to enter industry in ever-increasing quantities is magnesium. It is distinctly lighter than aluminum (specific gravity 1.74, compared to aluminum specific gravity 2.7), and can be made into alloys which are almost as strong as those of aluminum. Because of this advantage of light weight, the high magnesium alloys are beginning to appear in aircraft construction. In that field, where light weight is paramount in stratosphere balloons, the gondolas are made of Dow metal, which is a trade name for certain magnesium alloys. Within the past 2 years great advances have been made in improving the corrosion resistance of these alloys so that now magnesium at 28 to 30 cents a pound is beginning to be a competitor of aluminum at approximately 20 cents a pound. As magnesium alloys improve, there will certainly be an interesting commercial conflict between these two materials.

Though there is only about one-quarter as much magnesium in the earth's crust as there is of aluminum, it may eventually be the less expensive material of the two because it is inherently easier to recover as a metal, though it is still very difficult to work. It is obtained from some salt well brines. There are large deposits of various magnesium ores, and the metal could even be recovered from sea water if it became necessary to do so. The supply of magnesium is practically limitless and the extent of the market probably depends upon the success of fundamental research in making certain products. At the present time there is a large demand from some European countries for magnesium to be put into incendiary bombs. It is hoped that this market is only temporary and it is to be said to the credit of the American producers that they have made no attempt to cultivate it.

Electrometallurgical processes, of course, require a great deal of power. Power costs will undoubtedly be an increasingly important item in the future.

Table 28 gives the approximate power consumption for the production and refinement of the metals which now use electricity in their production.

TABLE 28.—*Power consumption in electrical production and refinement*

Summary of available figures (mostly from Koehler and J. Mantell.)
Aluminum production, 10–12 kilowatt-hours per pound, electrolytic.
Copper production, 1.2 kilowatt-hours per pound, electrolytic.
Copper refinement, 0.06–0.10 kilowatt-hour per pound, electrolytic.
Iron production, 0.08 kilowatt-hour per pound, furnace.
Steel refining duplex, 0.05–0.10 kilowatt-hour per pound, furnace.
Steel melting scrap, 0.35 kilowatt-hour per pound, furnace.
Brass melting copper, 0.14 kilowatt-hour per pound, furnace.
Brass melting zinc, 0.04 kilowatt-hour per pound, furnace.
Silicon production, 6.5 kilowatt-hours per pound, furnace.
Manganese production (pilot plant), 2 kilowatt-hours per pound, electrolytic.
Cadmium production, 0.8–1.3 kilowatt-hours per pound, electrolytic.
Zinc production, 1.4–1.6 kilowatt-hours per pound, electrolytic.
Tin recovery from scrap plate, 0.085 kilowatt-hour per pound, electrolytic.
Nickel refining, 1.1 kilowatt-hours per pound, electrolytic.
Magnesium production, 8 kilowatt-hours per pound, electrolytic.

As electrometallurgical and electrochemical industries advance, it is quite feasible to expect certain shifts in industry, probably toward sources of cheap power. It would be well to point out that progress is continually being made in the field of the cheap production of electric power from solid fuel, and we are still in a period of increasing efficiency of our power plants. In the past it has been common to assume that water power is the cheapest, but this picture is gradually changing and it may very well be that the future centers of power production will be in the neighborhood of those large coal-mining districts where sufficient water is available for the operation of large steam-power plants.

Another item of ever-increasing importance in the field of fabrication of metals is that of welding, particularly electric welding. The tanks of acetylene for the portable gas welding outfit have been familiar in the industrial landscape for a number of years. But this type of welding did not enter into the field of factory fabrication to any great extent. The public probably first became aware of the presence of electric welding when they observed hooded men bonding the sections of street railways. The operation always took place behind a barricade with a large sign out in front, "Beware of the light." In the construction of buildings, in those areas not crippled by too many building restrictions, the buzz of the electric arc has now pretty well displaced the din of the riveting hammer, and welding is even entering the tradition-ridden field of shipbuilding.

Perhaps more important from the viewpoint of the average consumer is the advent of welding in manufacturing processes. The welded aluminum chair is one example, and it often seems as if the screw driver and the riveter's hammer are on the way to obsolescence.

In earlier days it was usually true that welding tended to spoil the character of the surrounding metal so that the finished piece was not as strong as it should be. The recent techniques, particularly on thin material, use very high currents for very short periods of time and there is no overheating of the surrounding metal and hence no deleterious effect. For instance, the modern metal radio tube is welded in an automatic machine which uses a current of the order of 10,000 amperes for the period of about 0.01 of a second, making butt welds which are practically perfect.

The spot weld is beginning to displace the rivets in the manufacturing of metal airplanes, though the manufacturers are still proceeding cautiously along this line because they are not sure of the fatigue characteristics of the surrounding metal. By using welding it is possible for them to cut the cost per joint to a fraction of the cost if rivets are used. Flash welding of automobile bodies has become a process of paramount importance.

At the present time, welding is only being used in a small proportion of the places where its use is justified. When the various forms of industrial and human inertia are overcome, it will unquestionably continue to decrease the cost of fabrication of all types of articles and structures and probably make possible many types of operation not now being used.

A relative newcomer to the field of practical metal working is "powder metallurgy." This is the art of producing a formed product from powders by hot or cold compression which, upon subsequent heat treating, shows characteristics not generally obtainable by orthodox processes. It is roughly analogous to the technique employed in the field of plastics. It started with the preparations of tungsten and molybdenum wires. The powders of the metals to be used must be carefully controlled as to particle size, purity, and mixing. They are molded under high pressure and sintered (incipient fusion) in an electric furnace with a reducing atmosphere. Temperatures are maintained at about two-thirds the melting point. These sintered metals produced by the process of powder metallurgy are now used in millions of bearings and bushings in automobiles and railway cars, in dental work, electrical parts, and welding rods. These combinations of the tricks of powder metallurgy make possible a number of adaptations of metals not otherwise possible, and in many cases give products which are far superior to those obtainable by any other method.

Nitriding steel is a process which came from the Krupp laboratories in Germany. It consists of heating special steels in an ammonia atmosphere which produces a very hard "nitrided" surface. Its use has grown rapidly in this country in the past 8 years. It is used chiefly to enable steel to resist wear in motor parts. Hardness and corrosion resistance are retained to temperatures up to 1,000° F. The process has an obvious use in the field of cutlery, for nitrided edges are much more permanent than those obtained in any other way. The author knows of one metallurgist who made his own safety-razor blade, sharpened it, and nitrided it. It has been used daily, without resharpening, for 2 years. Naturally, razor-blade manufacturers are not interested.

Impact Testing.—It has been found that the strength of metal is dependent not only upon the chemical and physical properties, and the temperature, but also upon the rate at which the stress is applied to a particular object. Some very fine quantitative work has been done by Dr. H. C. Mann at the Watertown Arsenal which has led to a quantitative evaluation of the relationship between the tensile strength of a metal and the velocity at which the stress is applied. This investigation was undertaken with the idea of explaining certain failures of steel under impact stresses, but it has resulted in a good deal of important fundamental information. It has been found that the tensile strength of a given piece of metal is practically constant for speeds of application of stress up to a given critical point. If the stress is applied more rapidly than this critical value, then the tensile strength falls off rapidly and in some cases, when the stress was applied so rapidly that the test specimens were broken in periods amounting to a microsecond or so, the metal showed almost no strength at all. This critical velocity for the application of stress amounted to from 100 to 200 feet per second for mild-carbon and low-alloy steels, and as high as 320 feet per second for some of the higher alloys. Stainless steel, curiously, had critical velocity as low as 5 or 6 feet per second. This information when carried further will undoubtedly point the way to the improvement of structures that are subject to very rapid vibration, such as airplane parts, for vibrations are nothing but very rapid applications of alternating stresses. This fundamental study will undoubtedly be heard from more in the future.

Centrifugal Casting.—A number of years ago it was proposed to make cast-iron cylinders by pouring molten iron into a rapidly rotating cylindrical shell, thus eliminating the slow and costly proceeding of making sand-mold castings. This process was first used about 1920 for making bronze castings at Sandusky, Ohio. It has been successfully used in the past few years in the centrifugal casting of iron pipe,

at Birmingham, Ala. The United States War Department has carried this idea considerably further and it is now producing gun barrels by this ingenious method. It is necessary for the guns to be made of carefully controlled alloy steel, and this is done by pouring the molten steel at approximately 1,500° C. into a horizontal rotating mold which, by the end of the cast, is rotating as high as 1,500 rotations per minute. The process is proving very successful and will probably replace the old-time, slow, expensive, and wasteful process of making gun barrels from large steel forgings. By this process there is much less waste, the total time of manufacture is cut to a small fraction of that required formerly, and the properties of the metal cast in this way are distinctly better and more uniform than those produced by the old-time forging methods. One of the chief advantages in times of emergency would be the fact that small plants could turn out guns very much more rapidly than the very expensive forging plants.

The machined barrels are cold-worked from the inside by the application of hydraulic pressure of the order of 100,000 pounds per square inch.

This process of centrifugal casting will undoubtedly be developed for use of other shapes of steel alloys and will probably have a distinct effect upon the steel-forging business of the future.

The ideal shape for this type of manufacture, of course, is the cylinder, but it possibly can be used for making any symmetrical shape, and it is even likely that strong nonsymmetrical castings can be produced in this way.

In the years gone by a good deal of zinc was used for making zinc-base die castings, but they were not particularly satisfactory, for they would corrode badly and often disintegrate within a year's time. Fundamental research showed that the instability of the alloy used in making die castings was due to a trace of cadmium in the zinc. Then some American concerns began producing commercial zinc metal which, instead of being 99.9 percent pure, was 99.99 percent pure, and practically cadmium free. This new, extremely pure zinc, produced either electrolytically or by vacuum distillation in a fractionating column, was found to make zinc alloy die castings which were infinitely superior to those formerly used. Consequently zinc die castings can be made very cheaply and their use has expanded enormously, particularly in the automobile field. They are now being used, and giving a great deal of satisfaction, for carburetors, radiator grills, door handles, and window frames. In some cars, as many as 40 objects are made cheaply and very satisfactorily from zinc die castings. This material, which is the direct result of a piece of fundamental research which had no apparent usefulness, is now bringing zinc into the field in competition in some cases with steel and in other cases with plastics, and the customer gets better material at decreased cost.

One of the most significant changes in the fabrication of articles in the present century came with the introduction of the high-speed tool steels. The ordinary carbon steel can be made into excellent cutting tools, but it does not retain its properties of hardness and strength at high temperatures. When a tool is used to cut metal, as in a lathe, no matter how sharp the tool may be and how perfect the cut, there is a large amount of local heating. Hence, with the old type of tool steel, a metal object had to be cut or shaped very slowly.

With the introduction of the high-speed tool steel (discovered by White and Taylor of the Bethlehem Steel Co. in 1900 as the result of a fortunate accident which successfully terminated a long series of expensive experiments), the usable cutting speeds were increased four or fivefold. Within a few years there was a revolution in those industries which depend upon cutting tools for the fabrication of articles. All the old machines became obsolete and quantity of production was enormously increased.

This introduction of one simple improvement so changed the industrial picture in this country that the efficiency of all industries underwent an estimated increase of some 15 percent. In other words, the increased productivity of all industries, due to the introduction of high-speed tool steel amounted to about 8 billion dollars per year. All this was accomplished by the utilization of about 20 million dollars worth of these special steels per year plus, of course, the required additional investments in new machines. This is one of the most phenomenal examples of the immense effect of one small development. This development has been further accelerated by the use of Haynes Stellite as a hard tool material.

Just as there was a revolution occasioned by a new tool material in the first part of this century, there is, at the present time, new material which may eventually cause as great an increase in production as did the high-speed tool steels.

A few years ago Dr. Karl Schröter, of the Osram Lamp Works, Berlin, started out on a program of research to find a material which would be sufficiently hard to replace a diamond in the wire-drawing operations of this lamp works. He found what he wanted in tungsten carbide. It was not only satisfactory for the wire-drawing operations, but it was found that when the particles of this extremely hard material were imbedded in and cemented together with cobalt the resulting combination had not only extreme hardness, but also sufficient strength to stand the strain of machine

cutting. Moreover, it retained its properties at red heat.

This new material was introduced into America in 1928 on a small scale. The General Electric Co. holds the United States patent rights and there are a number of licensees. It was found that by using these tungsten carbide tools not only could some hitherto unworkable materials be machined, but the speed of cutting certain materials could be increased several fold over that of the high-speed tool-steel operations, for the tool can run red hot and still be perfectly satisfactory. However, due to some peculiarity of the surface-wetting characteristics, it was not suitable for cutting steel so its principal application was in the cutting of cast iron and the nonferrous metals and for wire-drawing dies. Though this had a certain effect in increasing production in these materials, it was only touching a very small proportion of the machine industry. Research continued. Some improvements in the material were made by the introduction of tantalum carbide by the Fansteel Products Co. Development work continued in Germany under the direction of Dr. Karl Schröter, and a new material is now available which consists of a mixture of tungsten and titanium carbides cemented with cobalt. This is perfectly satisfactory for cutting steel and it has been found to have 60 times the life in operation that the original cemented tungsten carbide had.

The introduction of this new material is enabling the cutting speeds to go up and up. The limiting factor in cutting speed in this material with this type of tool is no longer the property of the material itself, but the rather peculiar and unexpected difficulty of getting rid of the chips. The study of chips is now a basic problem in metallurgy. The significance of this new development can only be estimated when it is realized that it has only invaded a very small proportion of the field at the present time. There is no question but that it will make many machines now in use obsolete and the productivity throughout the industries as a whole will eventually again be markedly increased, certainly in the order of millions, perhaps of billions of dollars per year.

Processes Hopeful but Unproven

Once in a long time a revolutionary process enters industry. Often it comes in by the back door—that is, from someone outside the particular industry involved. It seems strange that this should be true, particularly for those industries which maintain competent, alert research staffs. Nevertheless, outside individuals frequently come along with absurd ideas which any expert knows cannot work for a dozen perfectly good reasons but which eventually do work and become important despite all opposition. It merely demonstrates the very fortunate fact that no organization, no matter how powerful or efficient, has a monopoly on information.

Most steel men knew that Henry Bessemer's idea of making steel by blowing air through molten iron was absurd. Despite universal ridicule Bessemer built his own plant and revolutionized steel making. The ridiculers are lost to history. William Siemens knew that his open-hearth process for making steel was fundamentally sound. No one else believed it until he had demonstrated its success in the steel plant he built himself. After the steel makers had all climbed on the wagon with him many of them contended that they had thought of it first. Hadfield discovered that steels containing 13 percent or more of manganese were strong, tough, and very desirable. He couldn't convince even his own father, a foundry owner, that this was true. Eventually, Hadfield's work led to the opening of the entire field of alloy steels. Not many years ago all the electroexperts knew that chromium plating could never be practical—all but one or two. Millions of automobile bumpers now show evidence of the experts' error. Before 1908 it was known that it was impossible to make ductile tungsten wire, but in that year Dr. W. D. Coolidge, of the General Electric Laboratory, forced that tradition out the window.

There are several developments in the making now which, though still unproven, stand a chance of having a great deal of influence in future metallurgy. The author, of course, is not bold enough to claim infallibility in picking the winners but here are a few inventions that have graduated from the laboratory to the pilot-plant stage and will bear watching. Their practicality may not be tested for many years to come.

There is a definitely increasing tendency to reduce the amount of labor required for turning the steel ingot into some finished product. One may then ask the question "Why is it necessary to pour molten steel into an ingot and allow it to solidify and then reheat it before sending it to the rolls? Why not realize the ultimate process of labor saving by pouring molten steel between water-cooled rolls and producing the finished product without any intermediate steps of casting, cooling, and reheating?" These are legitimate questions.

The Hazelett process (Hazelett Metals, Inc.) for the direct rolling of metals has been in the developmental stage in the brass and copper industry for several years. At least a million pounds of brass sheet have been rolled directly from the molten metal by this method. It is not only a labor saver; it also produces metal with some distinctly improved qualities. It has been utilized for the rolling of copper. The use of this method is spreading to other countries and is probably more advanced in Germany than it is here.

Recently a 20-inch mill for direct rolling of brass and copper was shipped from this country to Japan. It has the capacity of 1 ton in 4 minutes. Similar mills are in operation in this country. Because of the fact that steel melts at a much higher temperature than brass or copper, the difficulties of direct rolling of steel are much greater, but development work is going ahead very rapidly in this field. One company in Baltimore has recently installed a mill for the development work on the direct rolling of steel as well as aluminum sheet.

This direct-rolling process is not yet a major item in the production picture but there is little doubt that it will rapidly become so in the nonferrous field and if the troublesome difficulties are overcome will undoubtedly have a decided effect upon the labor required in the production of finished products. This tendency toward increased efficiency of production will unquestionably enter even further into the problem of technological unemployment in the future than it has in the past. Moreover, there is some good evidence that metal sheet produced by this process is inherently better than that rolled from ingots.

One way to prevent iron from rusting is to cover it with a layer of zinc or tin. Pure aluminum is noncorrosive so it should be ideal, for such a protective coating. There have been many failures in attempts to get satisfactory aluminum coatings on steel, but recent developments are very encouraging. The most successful results to date seem to have been obtained by the Fink process. This new process produces a tight coating, practically free from pinholes, by the process of dipping the steel which has been thoroughly cleaned and activated by hydrogen, into a bath of molten aluminum. After this plate or wire has been coated, it can be freely rolled or drawn. The surface is then covered with an aluminum-iron alloy which resists a wide variety of corrosive attacks. The plated sheet can be used to displace tin in many food containers. Its cost lies between that of tin plate and galvanizing and if its corrosion resistance proves to be better than that of the zinc coating, it may replace a great deal of the galvanized iron of the country. It might prove to be a very effective means of giving permanent protection to structural steel, even in the open structures such as bridges or the closed structures such as steel-framed buildings. It opens up a large number of possibilities in the field of airplane construction for the light aluminum alloys are not entirely satisfactory because of the fact that they must be heat treated with extreme care in order to retain reliable strength characteristics. The stainless steels actually have more strength per pound than the aluminum alloys, and hence are beginning to creep into the field of the all-metal airplane. At least one company in this country is making planes of stainless steel and probably more will follow. However, if an ordinary high strength steel can be successfully coated with aluminum it may prove to be satisfactory and inexpensive. Hence it has a possibility of changing the aircraft picture. These are possibilities and not promises, but there seems to be little doubt that this or a similar process will play an important part in our future battle with corrosion. There are already two plants producing this material in Germany, one in France, and one in Japan. One plant has recently started production in this country at Knoxville, Tenn.

The history of aluminum production in this country is the history of the Aluminum Co. of America. This corporation took the Hall process for depositing aluminum from a fused cryolite bath (which was first successful 50 years ago) and has built up an immense and world-wide industry against heavy odds. They have performed a magnificent task of pioneering, investigating, and developing a new material, and educating the public to use it. They have been so outstanding in the field that they have been practically the sole producers in this country. From the beginning they have had what was apparently a satisfactory process of manufacture and have not found it necessary to make any fundamental changes since they first started in the business 50 years ago. Their competent and very active research staff apparently has carefully investigated all known possibilities, and they have decided that the original ore-purification and extraction processes are still best. Nevertheless, there are at least three outside processes which are well in the developmental stage which may have a distinct effect in the relatively near future upon the price and hence the availability of aluminum. With the price wavering in the vicinity of 20 cents per pound, aluminum is still, when compared to steel, an expensive metal. It will forever remain more expensive than steel because, while it is abundant, it is very difficult to persuade the metal to leave the chemical combination with oxygen. It requires approximately 10 kilowatt-hours per pound of aluminum to effect this separation. Hence power cost alone makes it inherently more expensive than steel. Aluminum Co. equipment represents an investment of approximately 1 dollar per pound per year installed capacity for metal production. Hence carrying charges, or investment, amount to about 6 cents per pound of aluminum—a heavy burden.

It is difficult to separate aluminum from the other metal constituents. Hence the material used for making the metal must be practically free from iron, silicon, and titanium. With the Hall process, as it is now used, it is necessary to have relatively pure bauxite to begin with and it is necessary to refine it by expensive leaching processes.

Dozens of inventors have worked more or less successfully upon processes which will permit the use of lower grade ores than are now necessary, and for cheaper methods of extraction. There is one process based on the Hunyadi patents which uses the ordinary grade of bauxite as a raw material, but which is not disturbed by the presence of silica so it can use a lower grade of material and is somewhat less expensive than the present process. It will probably have a thorough trial in quantity production within the next few years.

There are at least three apparently feasible processes for extracting alumina for the production of aluminum which will have byproducts to help pay the expense and hence can effectively lower the price of production. One of these, a wet leaching process using Utah alunite as a raw material, permits the recovery of potassium sulphate as a byproduct. Another process recently developed by the United States Bureau of Mines uses the same raw material, but refines it by distillation and slagging of materials from electric furnaces. It produces potassium oxide as a byproduct. In the matter of cost, this process seems somewhat more feasible.

It has long been considered that it would be possible to make aluminum as a byproduct of cement manufacturing. There is at present such a process in the developmental stage, based on the Cowles patents, which bears considerable promise of success. This would make aluminum oxide as a byproduct of cement manufacture. This aluminum oxide could be later used as a source of aluminum metal. These processes which depend upon byproducts of course have the difficulty of keeping a balanced market between the two materials. This is often inconvenient though not necessarily insurmountable.

It is not possible to predict what is going to happen in the production end of the aluminum business, but it can be said that it seems much more likely than it did a few years ago that successful processes may be developed which will distinctly decrease the cost of the aluminum metal. The future may prove that the old process is still the best and the newer ones are valuable chiefly as threats on the cost of production. Whatever the situation, the cost of the metal will probably come down, for competition sometimes has wonderful results.

The electrolytic production of magnesium requires almost as great a power consumption as does aluminum. This makes it, then, inherently relatively expensive. However, magnesium has the advantage over aluminum that it can be recovered from its oxide through the medium of a reducing agent such as carbon in an electrict furnace. Such a method should result in a distinct saving in the cost of production. Until very recently the production of magnesium in this manner was not successful because of the fact that magnesium metal was always very readily reoxidized by the gases coming from the furnace. However, a process using carbon as a reducing agent has recently been developed by an Austrian, Hansgirg, and patented in this country, has come through the developmental stage and seems to be quite successful for the inexpensive production of magnesium metal. This process is now the subject of litigation in a patent suit and so its eventual development seems to be held up for the present. This or similar processes hold out definite prospects for the reduction of the cost of this extremely interesting metal.

Electrochemistry is beginning to enter into the electrolytic production of another valuable metal, namely, manganese. Manganese is a metal which is essential as an alloying material as well as a deoxidizer in the steel industry. It has been produced largely in the past as a ferroalloy reduced by means of silicon in electric furnaces using foreign ores, though there is a small manganese industry in this country. The Bureau of Mines has recently devised an electrolytic process for the production of manganese metal 99.9 percent pure, from an Arizona deposit of pyrolusite. The cost of production is estimated at about 5 cents a pound of pure metal. The process is now at the pilot plant stage. It is quite possible that it may enter production in the future.

Another material which is essential in the production of alloy steels, as well as for a coating metal, is chromium. It also is largely produced from foreign ores. There is a recently developed Bureau of Mines process for producing ferrochrome electrolytically from chromite ore. There is still considerable developmental work to be done on this, but if it proves feasible it will very likely be a partial outlet for the power to be produced at the Grand Coulee Dam. A new ore deposit of very significant size has recently been opened up in the Philippines and contains about 35 percent of chromium oxide. It would be feasible to ship this material to the Columbia River waterhead for electrolytic recovery of ferrochrome. There are also considerable deposits of this same type of ore in Montana and one county in Wyoming, which would be available in case of need.

Another interesting possible development in electrometallurgy may be forthcoming in the field of those metals such as aluminum and magnesium which are now produced by deposition from molten salt baths. It has been demonstrated in research laboratories that any metal can be deposited electrolytically from water solutions. It is possible to produce aluminum in this way though no process has yet proven commercially feasible. However, if a process for coating

aluminum on steel becomes widespread, it might prove possible to deposit aluminum directly on steel from a water solution without the necessity for going through the production of pure aluminum metal. The same might apply to a number of the other metals which may be used for coating. This might have a distinct effect upon the price of the coated metals in the future.

For a number of years there has been a small industry engaged in spraying molten metal on surfaces to form protective or decorative coatings on metals. The molten metal is sprayed on like paint and adheres to the cold surface. It is relatively inexpensive and has proven very effective for protection against some types of corrosion. Development in the past has been throttled by absurd restrictions and licensing fees by the patent holders, but the basic patents have now expired and there may be considerable expansion of this method in the future.

The newest development in welding, that of Dr. Antonio Longoria, has unfortunately been presented to the technical public with a type of publicity which usually announces the coming of the cure-all healer or the Hindu Yogi-man. All details have been kept strictly secret and there have been many mystifying intimations of the connection of this new invincible ray machine with death-rays and cures for cancer. Stripped of its smoke screen and rubbish, this new development does seem to be valuable, though of course not as valuable as claimed. The small compact device utilizes a high frequency current (1 to 2 million cycles). Unquestionably it does a near-perfect job of butt-welding thin copper and other nonferrous sheets, rapidly and with small power consumption. Apparently it is not, as claimed, a low temperature process but a true welding by fusion, though the fusion zone is kept confined to a very small area. There are many refinements which must yet be made but it is very probable that the process will be used a great deal in the inexpensive automatic fabrication of a host of articles. All such advances as this might obviously mean a decreasing cost of manufactured metal articles to the consumer and hence widespread social benefits and a much larger market.

It might be well to end this discussion of processes which may prove important with the mention of two which are often discussed, but which probably have no future. Millions of dollars have been spent in the past in an attempt to develop a satisfactory direct reduction process for making steel which would eliminate much of the expensive blast-furnace equipment. In the present method of manufacture the metal must first be made into crude pig iron which comes from the furnace in the molten state. Since the final product of steel manufacturing is a cold solid, it seems that a considerable saving in fuel and labor could be effected if the material were never allowed to arrive at the melting temperature. There are hundreds of patents on various "direct reduction" and "sponge iron" processes and undoubtedly a great many more patents will be issued in this field. However, there are a multitude of detailed difficulties involved which make it appear that this process can never compete with the present blast-furnace process even though on paper it should mean a saving in fuel and labor. Hence processes for making steel directly from ore probably do not belong in the near-future picture of ferrous metallurgy.

There have been repeated attempts in the past to use electric furnaces in place of blast furnaces for the production of pure iron. However, as long as fuel is cheap, it would seem that these electric processes cannot compete, though there is some ore smelted in electric furnaces in Sweden, Norway, Italy, and Japan. There have been some recent releases of information from a new Japanese process patented by Hideyuki Kikuchi which claims marvelous efficiency and low cost of production by electric methods. It is pictured as the revolutionary advance of the century. The patent covering the process, however, is so indefinite as to be meaningless, but one investigator has ascertained that the heart of the process is found in the impressing of high frequency field of a million cycles upon a mixture of ore and fuel which passes between the electrodes in a continuous stream. The Japanese Government is erecting an experimental plant at a cost of $150,000 at Yarwata to give the process a thorough trial. It seems that this new method may enable the Japanese to utilize their own low-grade iron sands but that it has no inherent advantages of low cost or ease of operation when good grade ores are obtainable. In this country, where we have an abundance of cheap fuel and still have a large amount of high-grade iron ores, we cannot expect electric power to displace the conventional iron blast furnace, though of course in the production of special materials the electric furnace might be used where power is very cheap and the source of fuel far away.

These few recent developments which bear promise of future significance are only the larger sized siftings from a quarry containing hundreds of metallurgical ideas. Even if none of them turn out to be winners in the next few decades there are other ideas in the making which will prove valuable. The successful future of our material society is reasonably assured as long as the present inventive flood keeps at full flow. If as many as 1 percent of the developments are worth while it is a good yield.

Substitute Processes and Materials

The sources of supply of our key metals (those most important in our industrial life) are discussed under the heading of strategic materials in the section dealing with the mineral industries. Although the United States is in a better position than any other country of the world in the matter of strategic metals, our situation is by no means ideal. Periodically, certain groups in this country have more or less serious brainstorms when they think of our possible future shortages of important metals. It seems that in case of war or a foreign corner on the market we would be placed in a very bad position. There is, of course, an element of truth in this fear, but an unbiased survey of the field shows that, while our supply of several metals would be seriously curtailed if we were suddenly shut off from the world metallurgical markets, it would be possible to take care of necessities with our home resources if we should apply existing knowledge of metallurgical processes to the working of low-grade ore deposits. For instance, though we now depend largely upon foreign ores for our supply of manganese the Bureau of Mines several years ago developed a feasible process for the securing of manganese from the iron ores of the Cuyuna Range of Minnesota. This process would not call for the construction of any new equipment because the ordinary iron blast furnace can be used for the separating of the manganese oxides. The development of a Bureau of Mines process for the electrolytic recovery of manganese from Arizona pyrolusite has been mentioned. We have a great deal of manganese in this country and processes are available for its recovery if they should be called for. In the past, a great deal of manganese has been thrown on the slag dump because of our wasteful blast-furnace methods. It is pleasing to note that during the past few years a great deal of basic open-hearth slag has been used in blast furnaces for the production of high-manganese pig iron. This trend of conservation is one which should be encouraged in every way possible. It is quite evident that without a great deal of inconvenience and probably with no great rise in price, we could handle our manganese production over a considerable period of time without calling on any foreign supplies. The same condition holds for several other metals which we now import.

The metallurgist has another weapon for fighting possible shortages, namely, substitution of one material for another. As far as resources are concerned, we are almost a tinless country but substitutes are gradually pushing tin from the status of a necessity to that of a mere convenience. Tinless solders and tinless bearing metals have been developed which are perfectly satisfactory. The possible use of aluminum coating in place of tin or steel would mean that tin could be dispensed with in the food-container field. Tin is losing some of its strategic importance but periodically there is pressure for tariff restrictions to encourage a hopeless "infant industry" based on our negligible tin resources.

Viewing strategic metals as a whole it becomes evident that changing technology is decidedly changing the picture because of possible substitutions. New processes are being made available to make our own ore deposits workable in case of need and substitution of one metal for another is becoming more and more feasible. Pressure groups are perennially active in asking for tariff restrictions to encourage the home production of all the strategic metals. In nearly all cases such proposals have been economically unsound for it has been a much more efficient procedure for us to get our supplies of certain materials from foreign sources. Moreover, in many cases where, though we have a considerable supply, the total amount is really limited, it would be distinctly foolish to build up a home industry which might in a short period of time deplete the deposits which we do happen to have. If our supply is limited it is probably best for us to save it for an emergency. However, the development of processes for the handling of a new material usually takes years so we should by all means encourage research in the field of production of these metals of which we have a limited supply but which we now obtain from foreign ores. Such processes can be developed and then be "put on the shelf" to await the time of need. There is still an immense amount of research that can be done in the field of the substitution of one metal for another. Obviously this type of research is not the kind which is attractive to commercial concerns for there is no prospect of immediate financial return. It would seem that this is a legitimate field for extensive research on the part of the technical bureaus of the Federal Government. Considerable work of this type has been done in the past and it should by all means be continued.

Effect of Technological Changes on Metal Producers and Consumers

Though the foregoing picture is made up of a rather extensive jumble of a great many facts, there is one item which seems to stand out very clearly, namely, that the production of the various metals is becoming more and more of a complicated business. One of the major effects of this tendency has been, and will continue to be, a distinct change in the type of personnel required. The old type rule-of-thumb man, who hadn't the slightest idea (scientifically speaking) of what he was doing, and only followed a certain technique because his predecessor had done so, is pass-

ing out of the picture. The college-trained men have, in spite of an immense amount of opposition, been making great improvements in the steel, as well as in almost every other metallurgical industry. Although all the operations are carried out for the most part by men who, though they may be skilled, have not had fundamental scientific training, it is becoming practically necessary to have the supervision of the industry under the hand of a man who has some understanding of fundamental physical chemistry and engineering principles. There has also been an increasing tendency for the technically trained college graduate to rise rapidly to the executive positions in corporations because of the fact that it is necessary for the people in charge to have a fundamental conception of what it is all about. There is a distinct shortage at the present time of the type of technically trained man who can keep production up to its present standards of quality and who can contribute something to the research in production and processes. As our metallurgical picture becomes more and more complex, and it undoubtedly will continue to do so, it will be increasingly important to have a larger supply of competently trained technical men and that is one commodity in which there now is certainly a shortage.

One tendency, which probably is unfortunate, is found in the fact that as processes become more and more complex, they progressively require more expensive equipment and personnel and hence tend to be a barrier in the way of small producers. One striking example is found in the foundry business. Customers are progressively demanding more and more that castings which come from a foundry shall be carefully and competently inspected for faults by means of X-ray of gamma-ray apparatus. Such apparatus is expensive and requires carefully trained men for its operation. The small foundry tends to object strenuously to such "foolishness" but it is a perfectly valid demand on the part of the customer and is something which probably must become routine in all future production. It is quite evident that this will be the straw that will break the camel's back for many a small producer. There is also an ever-increasing tendency to use alloy cast irons made by the introduction of nickel or molybdenum or other metals. Making this type of casting requires careful work and a knowledge of what one is trying to accomplish. It means that the old-time foundryman who operated mainly on tradition will probably have to pass out.

In the future, though the units of production may not necessarily have to be particularly large, they must be large enough to have sufficient equipment and a sufficiently competent personnel to stay abreast of the technical developments. Moreover, in order to stand the competition of other producers, it will probably be necessary for most units to do a certain amount of research or developmental work of their own. In general, then, it would seem that the future is certainly going to be an era of severe competition among metal producers and only the most competent units will survive.

The improved mechanical techniques all seem to be pointed toward labor saving. This tendency will unquestionably enter the picture of technological unemployment. Moreover, the ever improved quality of the product is going to make itself felt by fewer replacements and hence a smaller demand for the production of primary metal. Replacement, of course, is not always a function of quality, for obsolescence of a particular type of equipment very frequently enters for consideration. This has been particularly true in the automobile industry, but as any line of articles advances closer to perfection the obsolescence feature becomes less important. Unquestionably, manufacturers often try to prolong the item of obsolescence as much as possible by stretching out improvements over a maximum number of annual models. Then the amount of production seems to become a matter of the effectiveness of salesmanship rather than the length of life of the machine. However, as a manufactured article becomes better and better, the public becomes less susceptible to the "new model" racket. A closely related item is that which might be called "change of styles." Of course, the fads in metal products are not as swiftly changing and as disastrous as those in women's clothing, but it is an item which is very decidedly emphasized in the sales department. Replacement from this cause will undoubtedly always continue, but as far as the primary-metal producer is concerned, it is very likely that an increasingly large proportion of the metal used for the gadgets of temporary fancy will come back as scrap. Hence, unless unforeseen large outlets are found for more and more metal products, it is very likely that the amount of production of primary metals in the near future will not increase materially.

Competition among metal producers is not only among those who make the same kind of material; there also is a great competition between materials themselves, and in nearly all cases the material which gives the most for the money is the one which wins. For instance, plastics sometimes replace steel, as in the window frames of a Ford car. In other cars, zinc die castings are replacing steel. In the airplane field stainless steel is beginning to compete with the aluminum alloys. Welded steel sections are very successfully competing in many case with castings or forgings. There are literally hundreds of minor competitors between one type of alloy and another as regards cor-

rosion resistance, or stability at high temperatures. Magnesium is a direct and dangerous competitor with aluminum and aluminum coats on steel may compete with galvanized iron. In some cases a material may be so distinctly outstanding as to rule the field for a while, but usually there comes a competitor which gives it a race.

It would seem that the future metal industry will be permanently hitched to a consumer's market, for all the trends seem to be pointed toward a definite benefit to the consumer. Improved quality of products means longer life, lower total cost, and fewer replacements. On the other hand, and this is also an aid to the producer, improved quality and improved breadth of service ability of the alloys means new uses. Some of these uses are entirely new and some are replacement of one material for another.

One striking example of substitution of one metal for another is found in a recently completed 32-cubic yard dipper for a power shovel built by the Marion Steam Shovel Co. The total weight of the dipper is about 78,000 pounds, about half of this weight being aluminum alloy. The saving in weight brought about by the partial substitution of aluminum for steel gave a shovel of a working capacity one-third greater than it would have been if the construction had been entirely of steel.

One of the large users of the special steels is the chemical industry, particularly if this includes petroleum. When high temperatures and pressures are required, it is necessary to have metals which will retain strength and corrosion resistance at red heat. As a result of fundamental studies of properties of metals at high temperatures, it is now possible for industries to carry on chemical reactions and make products which would not have been possible a relatively few years ago. This eventually means more, and less expensive, products to the ultimate consumer.

Modern high-pressure steam plants have been made possible by modern steels, but power-plant designers want even better high-temperature steels and are waiting to get them.

Improved techniques of fabrication mean less expensive and new items for many consumer uses. Household ware of various kinds becomes more satisfactory and less expensive. If certain methods of putting a new type of decorative coat on metals are developed, it will be possible to expand the use of the metals in household articles a great deal.

Probably no single item will play as important a part in future fabrication as welding. As this process is developed toward perfection, we may expect eventually that all of our boilers, ships, buildings, bridges, airplanes, cars, chairs, and tables will be of almost exclusively welded construction. They will be much more satisfactory than at present and be produced at much less expense. All of these items tend to expand the market through decreasing cost. It appears that the only avenue which can lead to a larger use of metal in the future must be along this path of lowering the over-all cost to the consumer.

One generally unseen but happy result of the improvement of methods for combatting corrosion is found in improved safety of transportation. Railroad trains, automobiles, and airplanes are now much less likely to fail in service than they were even a relatively few years ago because the vital parts are less subject to the ill effects of corrosion.

There seems to be little doubt that metals are going to be one of the most important instruments in the gradual raising of the average standard of living for some time to come. Until our resources and ingenuity begin to decline there will be more and better metal objects in our lives than ever before. There will also be many more objects of many other kinds of materials. They all go together. The physical existence of the human race is certainly going to be greatly improved. This will all be an unhampered benefit to the consumer. It will probably result in the gradual expansion of business for metal fabricators, though competition between materials will be increasingly severe. But for several reasons which have been discussed elsewhere, there probably will not be a proportional increase in the total amount of primary metal production.

Possible New Markets

The optimists who view a metal civilization of the future as a boundless reservoir where an infinite quantity of new metals can be dumped are probably going to be disappointed. As has been pointed out, improved quality of production and an increased efficiency for the handling of scrap are probably going to prevent the rise of metal production to any phenomenal heights. This does not mean, of course, that we will not have a slow and healthy expansion of the metal industries for some time to come but only that there is no real boom in sight, particularly in the production of raw materials.

The automobile industry visualizes a tremendous expansion in the use of cars in this country. Of course, one cannot say how near we are to saturation in the American car market, but it is well to point out that we are not so very far from the figure of one car per family and it is doubtful if all America desires to be made up of two-car families. Undoubtedly, as our economic condition improves there will be an outlet for several million more cars which will go to people who do not now enjoy this convenience, but there is a limit. It might be pointed out that one limiting factor

in the desire to own a car is the present crowded condition of the average highway. If highways are distinctly improved, then there probably will be a noticeable increase in the demand for cars. In congested cities such as New York or Chicago, a car is very often a liability rather than an asset. If the automobile manufacturers wish to expand their market, they might well take steps to urge the decentralization of our population, for the yearning for a motorcar is felt strongest when there is truly an open road ahead. Though the automobile industry will probably expand to a certain extent, it is very likely that improved quality of production, decreasing frequency of failures, and slower rates of obsolescence will tend to just about equalize the possible expanding market.

There are some forward-looking individuals who visualize an immense outlet for iron in the remaking of our highways. There is one company in Toledo, Ohio, which is manufacturing triangular cast iron paving blocks for the purpose of making iron roads. They see an outlet for 200 million tons of iron in this country if all the rural highways were refaced in this manner. This would amount to about one-fifth of all the iron that ever has been produced in this country. This type of roadway has been used in France and England for certain limited areas of hard usage, but there are inherent disadvantages which would seem difficult to overcome. Unquestionably, if it could be used for inexpensive and satisfactory roads, it would represent an immense new market, but it is not an item that can be counted upon.

As power rates become less and less, the average American household will become more and more electrified and we may expect a considerable expansion in the use of metals in electric equipment. For instance, the market for electric refrigerators at the present time is only about 35 percent saturated in those homes which are wired for electricity and about 50 percent saturated with respect to electric washing machines. There are a multitude of other electrical gadgets which are far from the saturation point, but most of them do not represent a very large use of metal. In making an estimate of this market it must be remembered that electric refrigerators and washing machines are now so satisfactory that they operate a large number of years without replacement and so a market for these items cannot expand permanently.

Another item which is ballyhooed a great deal is that of air-conditioning equipment in homes. The statements on this matter should probably be minimized for such equipment is inherently expensive, not only to install, but also to operate. Complete air-conditioning equipment for the average home must cost about as much to install and operate as the present-day higher-priced automobile, and it is very likely that this equipment can never have a very wide market. Probably most large office buildings and certainly all large auditoriums and large stores and hotels will eventually be air-conditioned and there will be a considerable outlet for this type of equipment. In the household field there will probably be a very good demand for small units which will cool and dehumidify the air in one or two rooms during certain parts of the year. This may eventually represent a fairly large market for equipment manufacturers but will not cause a very large percentage change in the total consumption of metals. It is quite feasible to assume that a great many homes will eventually be equipped with auxiliary equipment which will enable the heating plant to control the humidity and air circulation as well as the winter temperature of the house, but this is by no means a complete air-conditioning equipment and does not represent the size of market that is often supposed.

The most feasible place to look for a new large market for metal at the present time is in the field of the prefabricated house. In the past few years the concerns which have been interested in introducing a prefabricated house for the American people have very foolishly followed the policy of declaring that there is only one possible material from which a house could be made, and that was the one that they were selling. We have been confronted with the all-steel house, the nearly all-glass house, the all-copper, the all-brick, and the all-artificial-stone house until the situation became absurd. Within the past year or so it has become evident that a more rational viewpoint has been taken and a feasible combination of materials has been started on its way toward the making of a satisfactory prefabricated house.

This field has a great many possibilities, but the market will probably expand very slowly. In the first place, there is as yet no completely satisfactory type of construction. In general, the most satisfactory house that can be prefabricated in a price range which can interest the average American would be a dwelling with a steel frame covered on the exterior with some type of asbestos cement board and on the inside with some type of pressed board. There would be wooden floors and a flat roof. It is only within the past year that the price of such a dwelling, erected, has come within the price range of the conventional wood construction. The selling points for these new houses cannot yet be on the basis of a great saving in money, though there is some reason to believe that they will be better than cheap frame houses.

Viewing the market as a whole, if we are to retain our present standards of housing for the next genera-

tion, it will require the construction of approximately three-quarters of a million dwelling units per year. With the type of construction which now seems most feasible, we could expect a maximum use of steel of less than 5 tons per dwelling unit. If, then, all the housing of the country were suddenly thrown over to a prefabricated steel frame construction, we could expect an expansion of less than 10 percent in the production of steel. This certainly does not coincide with the phenomenal growth to be expected according to some enthusiasts.

With the conventional type of wood-frame house, about 45 percent of the total cost of construction goes into labor. With a properly prefabricated house labor costs should certainly be cut in half and eventually would become even less. Hence, it seems as if it might be possible, when demand justifies mass production, to make perfectly satisfactory houses at a much lower cost than at present. If satisfactory prefabricated houses could be erected at a cost of some $500 per room, then we might expect a truly increasing market and a distinct increase in the use of steel. The trend, of course, in the cost of homes has been the other way. Figure 71 shows the cost of the average automobile since 1910 and the cost of the average house over the same period. The automobile cost has gone down very rapidly and the house cost has gone up just as rapidly. Obviously, there is a very definite reason for bringing the house cost trend down with the other good things of life.

In estimating the possible expanding market, however, it must be remembered that prefabricated houses will be less expensive by virtue of the fact that they will require less labor for erection. As they begin to invade the market, as they undoubtedly will, there is going to be very serious opposition on the part of organized labor. This may slow up the production, though it certainly will not stop it. In those areas where land values are absurdly high, savings in house-building costs may have little effect. An expanding housing program can easily be wrecked by real-estate speculators. Another deterring item will be the matter of public acceptance, for after all the appearance of the new type of house is different from that to which we are accustomed and it will take a very careful campaign of genteel salesmanship to make the prefabricated type of house popular with the American public. Hence, though this type of dwelling will undoubtedly affect the metal market in the future, it is very likely that it will not be a major item for the next 10 years, though by the end of this generation it may have led to a distinct rise in the standard of our living and will have utilized a good many million tons of new steel, as well as a considerable quantity of other metals.

The Field of Research

It is quite evident that the backbone of our technical development has been the item of research. When one makes such a statement he must of course define research in its broadest terms as including not only the activities in special laboratories, but also those modifications and "shots in the dark" which an inspired or desperate plant operator often makes.

Since we have made a great number of improvements in the past through the medium of research, and since a great deal has been accomplished, it might seem to some people that most of the difficult problems have been solved and that it might be feasible to slow down on the expenditures for research and let matters coast along as they are for a while. Actually, the exact opposite is true, for the principal product of research up to the present time has simply been the formulation of more problems than we have ever had before. We are just on the verge of putting not only the metal industry, but all other industries, on a truly scientific basis so that we shall not only have more products, but infinitely better ones and at very much lowered costs to the public. Research is also extremely important in the problem of conserving of natural resources, not only for the convenience of this generation, but also for the absolute necessities of the future. Opinions on our natural resources appear to be divided into only two schools—those who believe we are practically at the end of the rope, and those who assume that we have an infinite supply of everything. The truth, of course, lies between and it is certainly well for everyone involved in the metal industry to remember that resources, after all, are finite and it is for the benefit of all that the best possible use should be made of them.

In the field of pure and applied metallurgy, scientific contributions of this country have been inferior to those of several of the foreign countries. In taking a laboratory curiosity or a pilot plant operation and expanding it 10,000-fold in order to produce millions of tons per year, America has been supreme. However, when one searches the records carefully for the ultimate source of the fundamental knowledge which is the background of a great many of our marvelous developments, he can have no particular pride in America's contribution and within the last few years our supremacy in the developments of the process ends of production has not been held by as large a margin as it used to be. In other words, the rest of the world is beginning to catch up in the production end of the game and in the past has been and probably at the present time still is, ahead in the studies of the fundamentals of metallurgical science.

Of course, if this were an ideal world it would make but little difference where the discoveries and inventions came from, but that unfortunately is not a situation which is approached in any sense of the word. If we, as a nation, are to stay ahead of the game it is absolutely essential that within the forthcoming years we must expend more and more effort upon obtaining the fundamental information which is necessary for an advancing civilization. Moreover, viewing the picture a little more minutely, there is going to be an era of ever-increasing competition not only between individual producers of one material, but between producers of different materials, and it is quite certain that only those who have a firm scientific background will be able to survive.

This does not mean, of course, that individual organizations or that we, as a nation, should try to obtain all possible information and then keep it sealed as secrets so that no other can benefit, for cooperation on information undoubtedly benefits all people concerned. But if we are to continue to lead it behooves us to make our share or more than our share of contributions. Most of the discoveries in the fundamental science of metallurgy have come from abroad. Outstanding exceptions to this statement included the Hall method for the production of aluminum (and even priority on this is disputed abroad), the Aston method of producing wrought iron, Coolidge's work on ductile tungsten, and development of high-speed steel by Taylor and White. Such fundamental things as the Bessemer process and the open-hearth process for the making of steel came from abroad. (Kelley, of this country claimed priority, but Bessemer is generally conceded to be the inventor and developer.) In the several processes now in the state of development which may have future significance and which have been discussed previously in this report, it may be there are several examples which will, a generation or so hence, be counted as fundamental contributions.

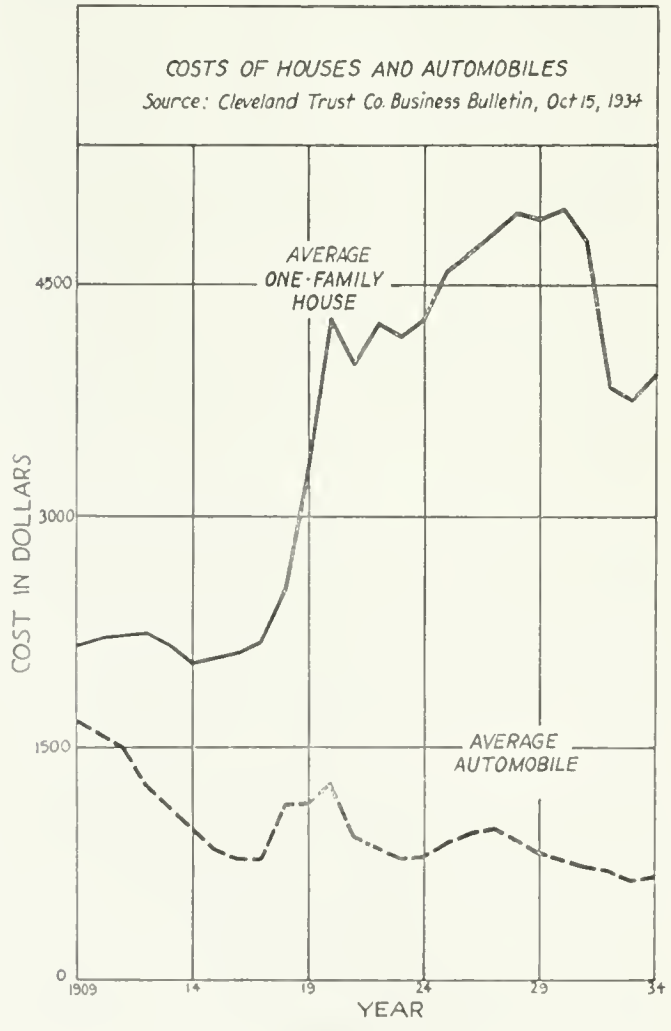

FIGURE 71.

As rather good evidence of the relative amount of fundamental information which is obtained in the United States and Germany, for instance, it should be pointed out that there are no periodicals dealing with iron and steel in this country which can in any way compare in the quality of scientific work reported in Stahl und Eisen or Archiv für das Eisenhüttenwesen. One competent research director (Dr. Robert F. Mehl, Carnegie Institute of Technology) made a careful investigation of the number of research articles which might have bearing upon metallurgy which had appeared in practically all of the scientific literature of the world for the past 2 years. In compiling the number of articles from various nations, he found the quantity produced was in the following ratios: Germany, seven; United States, four; England, two; Russia, two; France, one; Japan, one. It is quite significant to point out that Russia and Japan are both advancing very rapidly in this line of activity. In the quality of work, Russia suffers from a certain naïveté and youthful enthusiasm, and Japan is only recently beginning to stand on her own and be original in work, but both of them are becoming of increased importance. Of course, mere numbers of articles do not tell the whole story. It might be possible to apply a quality factor to these ratios given above and give a better evaluation of the true values of the contributions made by each country. However, it is very likely that the United States would not improve her position in the list by such a compilation. One reliable organization estimates that only one-hundredth as much money is invested in research by metallurgical industries as by chemical industries, per unit of invested capital in this country.

The countries which have just been discussed are better organized than we are for carrying on research for a special end. Their activities, of course, are very much more regimented than ours and they are being

urged by a spirit of extreme nationalism which tends to put a sort of wartime fervor into the research. It is very likely that in the long run this tendency will decrease the quality of the work, for there will be more and more tendency to have quick results for an immediate purpose and a considerable loss of fundamentality. Nevertheless, when a great deal of work is being done, some of it is important. Germany, for instance, has 15 institutes for metal research engaged exclusively in a study of the factors which may better their metal position.

In this country there is a considerable amount of money being spent on research by individual companies, though it is to be feared that only a small proportion of the appropriations which are labeled for research are actually being used in that field. Moreover, whatever fundamental research is carried on is usually hidden behind a foolish veil of secrecy. A great deal of it is being used in an investigation of improved process control or simply improvements in existing methods. This is all important and has effected immense improvements in the last few years, but the point is that the fundamental research which has no prospect of immediate application is the thing which is extremely important for the future. It must be remembered that there is always a great lag between discovery and application. Even worthwhile discoveries probably do not usually have a major effect upon industry for at least 10 years, and some things have lagged half a century or more. Hence, money expended on truly fundamental research is going to pay no immediate dividends, and even stands a fairly good chance of being a total loss to a commercial producer. Of course, there are many investigations that have an effect on metallurgy which in the original character of the research do not show any connection. A great deal of the work of physical chemistry might be classified in this way, and in the study of fundamental chemistry this certainly ranks with the others.

A great deal of fundamental research is now being carried on in American universities, but an unduly small proportion of it is on metallurgical problems. The number of students in our schools of metallurgy is appallingly small. Very little metallurgical work is done in the completely endowed research institutes. Some of the semiendowed institutes such as Mellon Institute of Industrial Research, or the Battelle Memorial Institute do excellent work, but there is not enough of it. The research projects are also often too closely tied to an immediate problem. The same applies to private laboratories maintained by consultants. Governmental bureaus always find it hard to justify expenditures for fundamental research that has no immediate application. Probably we will never have sufficient research until the industrial leaders become well saturated with the spirit of fundamental investigation. Progress in that direction is very slow and can only come about through education.

In the following, the author hazards a few suggestions on legitimate fields for future research of a more or less fundamental character. As far as the ultimate results are concerned, it makes but little difference where the work is done, whether it be in any of the many excellent laboratories of the universities, or those of industrial corporations, or those of Federal bureaus. The important item is to have the research done. Many of these problems have been partially investigated, though none of them completely.

1. A study of the fundamentals of the extraction of the newer metals—for instance, aluminum and magnesium—with an eye to more efficient and hence less expensive processes.

2. Feasible methods for the recovery of the minor metal constituents from iron ores.

3. Investigation of the fundamental physical chemistry of various means of concentrating extremely dilute solutions containing metal salts.

4. Investigation of the fundamental kinetics of all reduction processes.

5. Studies of the physical chemistry involved in the separation of impurities from metals.

6. A study and compilation of the important properties of very pure metals and their alloys. (There have been some truly important contributions along this line in recent years in certain sections of the United States Bureau of Mines Bulletin 296, Iron Oxide Reduction on Equilibria and in The Alloys of Iron Monograph of the Engineering Foundation. But the survey of the field has only begun and most of the fundamental knowledge for most of the metals is still lacking.)

7. Further studies of the more important effects of minute amounts of impurities upon metals.

8. Still further studies upon the fundamental chemistry and physics of corrosion, for this field is by no means completely understood.

9. Systematic determination of the properties of possible new alloys. There are almost limitless possibilities of combination and in many fields where we have but little idea of the properties.

10. An investigation into the properties and possibilities of the utilization of the now little known metals and their possible alloys. For example, titanium, lithium, sodium, and many of the rare earth metals.

11. Investigation of the variation of the position of a given metal in a time-temperature diagram. For instance, the tensile strength of a metal is dependent not only upon temperature, but also upon the time

which is consumed in applying a stress to it. The factor of time has been largely neglected and the complete story of a single property of a single metal has never yet been completely plotted.

12. Investigation of the possible substitution of one metal for another. This is particularly important for our strategic materials, but should also be carried to all possible substitutions, whether an immediate application is in sight or not.

13. Fundamental study of the basic phenomenon of heat treatment, and the effect of the physical distortion of metals. It must be emphasized that the properties of a metal are dependent not so much upon its chemical combinations as upon the physical make-up of the different units of its structure. Chemical analysis tells a little and the microscope tells a great deal more but there is still a great deal of doubt as to what is actually present in metals and as to how they behave when their environment is changed. The fundamental difficulties of corrosion and fatigue cannot be understood or conquered until there is complete knowledge of the chemical and physical structure of every possible bit of material which makes up a metal.

14. A study of the fundamentals of the cohesion of metals. As metals are drawn to finer and finer sections, they become stronger and stronger. It is estimated that a filament of glass 1 molecule in diameter would have a tensile strength of 1 million pounds per square inch. A filament of tungsten, in the same condition, would have a tensile strength of 12 million pounds per square inch. All of our actual metals of finite dimensions have strengths which are a very small fraction of these figures. It is not at all inconceivable that there is somewhere in the field of possibility a truly supermetal which will have strengths which approximate those of interatomic cohesion, but it is very certain that it will take a great deal of fundamental physical research to find such a metal.

To orient the reader in the field of research, the author wishes to point out that the great American public now spends but little more for fundamental research in all the sciences than it does for chewing gum.

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IX. THE CONSTRUCTION INDUSTRIES

By Lowell J. Chawner, Carlton S. Proctor, O. H. Ammann, H. W. Richardson, John C. Page, Malcolm Pirnie, and J. L. Harrison*

General Introduction [1]

Buildings, bridges, roads, and waterworks, in all ages, have been among the principal embodiments of community culture. They have, as a rule, been most actively constructed in times of comparative security and economic well-being although for centuries they were created almost wholly by slave labor or by the unaided strength of free men. In recent years, mechanical devices and scientific understanding of the forces of nature and the properties of materials have, with some exceptions, enlarged and are continuing to expand greatly man's capacity to create works and structures for his use and convenience.

As an industry construction is not always sharply defined but is generally understood to include the design and production of domestic shelter; enclosed space for commercial, manufacturing, public, and other purposes; substantial changes in the earth's topography; and fixed works for transportation and for the transmission of commodities such as water, gas, and electrical energy. The products of this industry ranging from single-family houses to bridges, dams, water purification and distributing systems, and streets and roads, are conspicuous in the differences in their technical development and in the physical conditions and geographic areas in which they are created.

The technological changes in many cases in recent years have been notable, in others almost wholly absent. The movement of large quantities of earth, for example, for roads, railroads, dams, and other works which 15 to 20 years ago required the use of many horse- or mule-team wagons or scrapers may now be done by large mechanical-driven bucket graders having a capacity of 5 to 15 times that of the dump wagons or fresno scrapers formerly used. The building of houses, however, as is well known, remains largely a handcraft operation. Lumber, brick, cement, roofing, pipe, and fixtures are for the most part still delivered to the site in much the same form and installed in much the same manner as they have been for many years. Recent developments in small-house construction may eventually have far-reaching effects but thus far have been used only to a limited extent.

Geographic, topographic, and other conditions also introduce widely different problems. Tunnel construction in congested areas of large cities presents peculiar difficulties in the disposal of excavated materials and requires special care in the use of explosives and in the protection of foundations to large buildings. In remote mountain areas the greatest problems are usually those of transporting men, materials, and equipment to the project. In building construction, soils of different physical and chemical composition and depth to rock at the site of a project make necessary essentially different types of foundations. Similar differences influence the design of a plant for the purification of water to remove turbidity, unpleasant taste, or pathogenic bacteria. In terms of its finished products, construction is thus principally a nonduplicating industry.

Contracting as a business is, furthermore, essentially mobile. Administrative and technical personnel, equipment, and to an important although lesser extent skilled mechanics often move over wide areas. Productive plant is not permanently situated as in most manufacturing industries but must be set up at each particular project. Increasing shop fabrication of materials and the use of mechanical equipment are, however, tending somewhat to fix the situs of employment of a larger portion of the total number of workers directly or indirectly dependent upon construction for their livelihood.

General Trends in Design, Materials, and Construction Methods

The rational engineering design of structures in the United States is hardly more than 70 years old even in its simplest forms. Recently these methods have been greatly perfected and extended. Models are now extensively used in the design of bridges, tall buildings, river channels, dams and many other works and structures; elaborate mathematical procedures are available for the analysis of stresses in building frames, arches, and monolithic concrete domes; and actual stress measurements upon completed structures under known loads are often made. These improvements in methods of design have been accompanied in many branches of engineering by extensive laboratory tests upon materials which have made possible increased safety and economy in many structures.

New materials such as glass brick, high-strength and rust-resisting steels, reinforced brickwork, fire-resisting treatments of lumber products, and the scientific proportioning of portland cement concrete have been

* The contributions of the several authors are indicated in the footnotes to the individual sections.

[1] Prepared by Lowell J. Chawner, Chief, Construction Economics Section, U. S. Bureau of Foreign and Domestic Commerce.

developed, in many cases quite extensively, during the past few years. A fuller description of these and other new materials is given in the sections of this report relating to the various types of construction.

In its broadest sense, construction includes both activities at the site of an improvement as well as in the manufacture and fabrication of essential materials. Although the several branches of construction have shown wide differences, especially during the past 15 years, there has been a general tendency to reduce the job-site operations and to deliver to the construction site materials more and more highly fabricated. This has been due in part to improved manufacturing and transportation facilities which have made possible some reduction in the costs of construction as well as increases in the size of the units which could be handled. Special efforts toward speeding up the erection of structures, in the case of building construction in the central areas of large cities, has also tended toward the use of highly fabricated units. Steel columns which 20 years ago were built up, sometimes on the site, using plates and angles are now rolled in large sections of sufficient size except for the heaviest loads. A similar development has taken place in steel bridge construction, where the members, and in many cases the completed trusses or girders, are completely shop-fabricated. The proportioning of concrete at a central plant, the transporting of it in trucks as large as 4 cubic yards in capacity, and delivery ready for placing; the fabrication of wallboard panels of wood, vegetable fiber, asbestos-cement, or gypsum; ready-cut structural members for small houses; and the complete shop fabrication of removable interior partitions, especially for office buildings, are further examples of this development.

The methods of construction on the site itself have also experienced important technical changes in many operations. Equipment such as trenching machines, concrete pavers, caterpillar-tread power shovels, and pneumatic-tired trucks have come into wide use during the past 15 or 20 years. Two of the most recent developments are the actual pumping of concrete at the rate of 40 to 60 cubic yards per hour and the drilling by continuous rotary methods of large caissons of 5 feet to 12 feet in diameter for bridge and building foundations.

Primary Effects of Technological Change

Technical improvements in construction are related, in important respects, to costs and to the size of the works and structures which are technically feasible. These two primary effects appear to be associated in many cases with secondary changes such as the enlargement of the volume of activity and employment, the stimulation of other industries, improved community health, and variations in the rate of urban growth. Single cause and effect in economic and social actions is, of course, exceedingly rare and the social effects of technological changes in construction are no exception to this general observation. It is believed, however, that some of the secondary changes just mentioned, even though not dominated by technology, are often determined by it to an important degree.

Long-term trends in construction costs frequently reflect the technical improvements in various types of construction. The differences in some of these trends are shown by the indexes which appear in chart 1. Although a number of factors such as labor productivity, contractor's profits, the prices of labor and materials, and the size of projects included from year to year enter into indexes of construction costs, they do not show the systematic differences between the various types which are clearly evident in the case of the technological factors. The construction of buildings during the past 15 years has experienced a number of technical improvements but, excepting those of the past year or two, they have not been conspicuous. However, grading and excavation for highways and railroads, as has already been observed, has seen a notable series of developments in the introduction of new equipment such as wheel scrapers, pneumatic-tired trucks of large capacity, loading machines, and heavy tractors. Power shovels have also increased greatly in mobility, ruggedness, speed, and economy of operation as well as in size. The largest shovels are actually much too large for most construction operations (they have a capacity only slightly less than that of an ordinary freight car) and are used for stripping purposes in open-pit coal mining operations. The index for bridge construction costs shown on figure 72 relates, subsequent to 1922, to structures built by State highway departments and is not based upon any single span or type of structure. Major improvements in highway bridge structures both concrete and steel are well known, but, excepting in the longer and heavier spans, have not been as notable as have been the technical changes in grading and excavating. The differences in the trends in the costs shown in this chart are very largely attributable to differences in technological developments.

New technical developments or improvements frequently make possible works and structures of a type or extent which otherwise would be impossible. Long span suspension bridges, such as the George Washington Bridge across the Hudson River at New York City, were made possible by the development of cold-drawn steel wire of high strength. Treatment plants for the purification of large quantities of turbid, bacteria-laden water for domestic use have been made possible only as chemistry and biology have developed the re-

quired processes. Modern reinforced concrete buildings and bridges have depended heavily upon new methods for the stress analysis of rigid structures, power equipment for mixing the concrete, and recent developments in the chemistry of cement. Subaqueous tunnels in soft materials required compressed air and the air lock before they could become a reality. For many years work under high pressures was retarded by inadequate knowledge of the physiological effects of compressed air.

General Economic and Social Effects

The secondary influences of technological changes in construction are more obscure as has already been observed. In many cases technical improvements have doubtless sustained activity and employment at levels which, very likely, would not otherwise have been maintained.

Through their effects upon costs, technical improvements have also enlarged the physical volume of works possible with a given allocation of funds particularly by public agencies. According to the estimates of the Bureau of Public Roads, the expenditure, which in 1922 built 100 miles of highway, would have built 124 miles of that same type of highway in 1930 and 170 miles in 1932. This was possible, not at the expense of wage rates which were substantially higher in 1930 than in 1922 and approximately the same in 1932 as they were 10 years before, but almost wholly through technical improvements in the various processes of highway construction.

The wide cyclical fluctuations in construction activity are influenced by many factors (not identical for all types of construction) such as the rate of increase in population in a given locality, interest rates, levels of prices and income, earnings of industrial corporations, the physical volume of production, the fiscal policies of governments, and many others. Technological change is only one of these factors. It may be observed, however, that the types of construction which have experienced the widest fluctuations during the past 15 years—factory, commercial, and residential building—are those in which technological change has been slight. Conversely, the types of construction in which technical development has been the greatest—highways, bridges, and dams—are those in which the volume of activity has been most nearly sustained at normal levels (see figure 73). It should not be maintained that the relatively moderate fluctuations in the latter types as well as those in waterworks and sewerage construction are the direct and sole result of technical progress in construction; but it is clear that this technical progress has not to any degree *increased* the fluctuations in the major types of construction

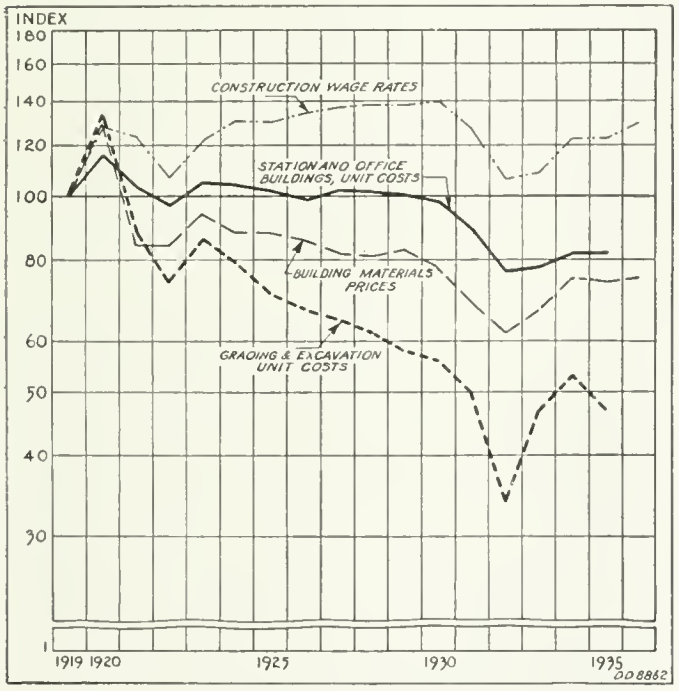

FIGURE 72. Indexes of construction costs, materials prices, and wage rates, 1919–36. 1919 = 100.

1. Construction wage rates, reported by the Engineering News-Record as actually paid in 20 cities in the United States. Arithmetic means of indexes of skilled and unskilled rates.
2. Station and office buildings, actual costs, United States Interstate Commerce Commission (1936 not yet available).
3. Building materials prices, United States Bureau of Labor Statistics.
4. Bridges, trestles, and culverts; grading and excavation; actual unit costs of completed work; 1922 to 1936, United States Bureau of Public Roads; 1915 to 1922, United States Interstate Commerce Commission.

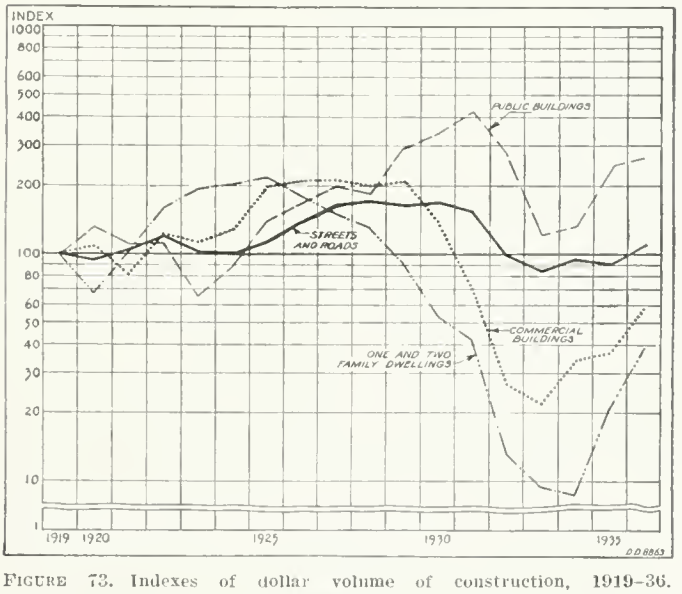

FIGURE 73. Indexes of dollar volume of construction, 1919–36. 1919 = 100.

1. Estimated total cost of one- and two-family dwellings, 1921–35, United States Bureau of Labor Statistics; 1919–21, Dun and Bradstreet, Inc., building permit values, all types, 120 identical cities.
2. Commercial buildings, streets and roads, bridges, public buildings, construction contracts awarded, total for the United States, estimated from F. W. Dodge Corporation reports for 27 States, 1919–22; 36 States, 1923–24; 37 States, 1925–35.

activity in recent years. Probably the most apparent difference disclosed by figure 73 is that between public and private construction. Sustained revenue from gasoline taxes and general public approval of expenditures for highways, waterworks, and sewage treatment plants, as well as Government policy favorable toward public works in periods of depression, have been very important factors in moderating the fluctuations in these types of construction during the past few years.

Related Trends In Other Industries

Technical trends in other industries, in many cases, also influence construction. For example, improvements in farming have lessened the proportion of our population required for the production of basic agricultural commodities. A century ago, more than three-fourths of the working population of this country was required to provide food and other necessaries from a reluctant soil and only a very few could be spared for the production of other conveniences of life. This condition has given way gradually to an age in which, according to the census of 1930, less than one-fourth of all gainfully employed persons in the United States were required on farms to provide basic agricultural commodities even in abundance. This change has resulted for many years in a shift of population from farm to city areas, particularly to the satellite communities of large metropolitan districts. This shift has been met by a movement away from the centers of these metropolitan areas because of unsanitary and congested housing conditions. These migrations, which the automobile and rapid-transit lines have largely made possible, have resulted in periods of marked building activity in the outskirts of urban areas, such as occurred from 1922 to 1928. The volume of residential building has been tremendously influenced by this process of urbanization and other types of construction have also been directly affected.

There appears to be no adequate justification for assuming that a sustained reversal of the long-time movement is to be expected, although the growth of cities is likely to be at a somewhat slower rate than that experienced in recent decades. The development to a commercially practicable stage of chemical processes which will further utilize products of the soil in the manufacture of essential industrial commodities such as fuel alcohol from specially developed starchy grains; oils from the tung tree or the soybean; or a wide variety of fabrics and plastic materials from young-growth timber may further retard the movement of population from the farm to the larger cities. In any event the rebuilding and modernization of cities, rather than the provision of shelter for new population, will probably represent a larger portion of urban construction activity than has been true in the past.

The phenomenal technical developments in the automobile industry during the past 25 years have also influenced construction in many ways. Indeed, the construction of highways and the manufacture of trucks and motorcars are particularly dependent one upon the other for their development. The introduction of new processes in chemical, steel, electrical machinery, and other industries is also frequently reflected in factory building activity.

In view of the important differences in the developments in the various types of construction several of them are discussed in some detail in the following pages. Not all types have been included. Railroad construction, for example, is not treated separately, but comments upon earth handling and bridge structures for highways are, in many important respects, applicable to railroads. Furthermore, the major technical developments affecting railroad transportation in recent years have not been in the construction of road and track but in rolling stock such as electric and Diesel-electric locomotives and lightweight streamlined trains. These improvements are discussed in the chapter of this report dealing with Technology and Transportation. It may be observed here, however, that the recent increases in train speed resulting from these mechanical improvements may also soon require construction changes in alinement, superelevation of curves, and improved smoothness of track. Although not all types of works and structures are included in the following pages, those which are discussed cover a wide range from small houses in which structural changes have been slight to highways in which recent technical progress has been particularly rapid.

Houses [2]

The provision of domestic shelter has been one of the slowest of the arts to respond to the widespread technical progress of recent times. To be sure, houses, in spite of their slow improvement, had for many years provided fairly adequately for the protection of human life against the hazards of severe weather and had made possible some privacy of individual and family life. Nevertheless, prior to the past 2 or 3 decades they had afforded, except for a very few, little convenience or comfort and, with the possible exception of very recent developments, have experienced little change in methods of fabrication on the site for a century or more.

From the point of view of technical improvement a distinction must be made between the housing structure, the facilities with which it is provided, and the community utilities with which it is served. Structurally, the detached houses which were built in the

[2] Prepared by Lowell J. Chawner, U. S. Bureau of Foreign and Domestic Commerce.

largest number in 1936 were not essentially different, as has just been observed, from many of those built in urban areas 100 years or more ago. In both 1936 and 1836 the materials: Brick, stone, sawed lumber, sand, and lime were delivered to the site in much the same form and erected in much the same manner, although the materials themselves are now produced by methods far in advance of those formerly used. Architecturally, the 1936 house may or may not have differed from its predecessors in appearance, depending in part upon the section of the country in which it was built. In plan, the interior today probably puts space to more sustained use and provides better light and outlook than did the 1836 house, but in general the architectural features of small houses have shown no notable changes. The facilities included, however, have experienced substantial improvements. Central heat, hot and cold running water, interior water closets, and installed baths, which were rarely provided 100 years ago are commonplace essentials in millions of houses today. Also community planning, frequently ignored in the hasty urban growth of the United States, has recently received increasing attention of designers. Light, air and open space, parks and playgrounds; protection against the noise and dangers of heavy traffic on streets and highways; and the arrangement of houses or other dwelling units in the interest of economy in providing for utilities are essential technical considerations of modern housing.

The technical availability as well as the extensive use of these facilities should not obscure the extent to which they are still economically unavailable to large groups of our people. For a surprising number of families, housing is still little more than shelter. Recent statistical inquiries into the condition of urban residential property have provided detailed measures of housing conditions not heretofore available. The most extensive of these inquiries,[3] conducted during the early months of 1934 in 64 cities throughout the United States disclosed a wide range of data on the crowding, facilities provided, the age and condition of structures, and other housing information. "Crowded" conditions (from one to two persons per room) were disclosed in 15.6 percent of the dwelling units surveyed. About one-fourth of the units in the 64 cities were without installed bathing facilities and almost one-fifth without private indoor water closets. In several of the cities the units which were without installed baths or water closets ran as high as half of the standing dwelling units. A number of these urban areas also showed more than one-fourth of the units to be without running water. These proportions, which may be accepted as roughly representative of all urban areas, although many of the oldest cities and poorest housing were not included, indicate that approximately 4 million urban American families are still without the barest essentials of "modern improvements" such as running water, private indoor water closets, and bathing facilities, in addition to possibly twice that number in rural areas. The wide technical advance in production methods which has brought the price of adequate clothing, books, a wholesome variety of foodstuffs, even of radios and automobiles in normal times within the range of nearly all persons still finds "modern" houses (not necessarily new ones) beyond the means of one-third to one-half of the families of the United States.

[3] Real Property Inventory, 1934, Department of Commerce, Bureau of Foreign and Domestic Commerce, Washington, D. C.

Facilities

During the past 15 years the technical developments in housing facilities have consisted largely in the gradually increasing adoption of the features which have already been mentioned and in the wider use of improved heating units, electricity, gas, elevators in multi-family units, refrigeration, and the use of domestic labor-saving devices largely powered by electricity. Insulation against heat transfer through walls and roof has also developed extensively since about 1930. This is also true of devices for air circulation, cleansing, and humidity control which are being installed in many new homes today. Air refrigeration is technically available but at present is within the reach of but few families.

Further technical developments in the insulation, heating, ventilation, and air cooling of houses and other buildings will undoubtedly be made during the next few years. One of the most interesting possibilities is the perfection of the electrically powered heat pump. It is theoretically possible, as was observed by Lord Kelvin in 1852, to reverse a refrigeration process and to use it for heating purposes. In moderate climates (where temperatures seldom go below 30° to 40° Fahrenheit) the efficiency of such a device may be as high as 300 to 500 percent; that is, a unit of electrical or mechanical energy may, by reversing the principles of the heat engine, transmit heat energy from a low temperature source to a higher temperature body in an amount three to five times that of the original electrical or mechanical energy applied. A few heat pumps of this type have actually been installed in England and in this country.[4] A combined installation for cooling in summer and heating in winter is attractive to contemplate and appears altogether possible in

[4] Refrigeration, A. R. Stevenson, Jr., Journal of the Franklin Institute, vol. 208, pp. 143–187, August 1929.

Two-Mill Commercial Heat, by Reversing Refrigeration Cycle, W. R. Chawner, Electrical West, Apr. 1, 1931, pp. 177–179.

The Heat Pump, T. G. N. Haldane, Engineers and Engineering, March 1930, pp. 64–72.

the southern and Pacific coast areas of the United States particularly where electrical energy is available at low cost.

One of the most far-reaching possible changes associated with housing facilities is not technical but social. Modes of living are likely to reflect the tremendous increase in the comforts and conveniences available under controlled conditions of temperature, humidity, and air cleanliness. It is noteworthy that the ultra-modern or twentieth century houses are dominated by the arrangement of interiors for comfortable living and by outlook rather than by external ornamentation. This development is likely to continue at an accelerated pace in the immediate future but will depend for its fullest exploitation and widest enjoyment upon the reduction in the costs of facilities attainable through improved industrial methods and large-scale production.

Materials and Methods of Construction

The technical developments in facilities have been accompanied by some, but, until quite recently, hardly comparable changes in the materials and methods of building the housing structure itself. Certain materials such as steel, copper, brass, aluminum, concrete, gypsum, and asbestos have extended their uses in the housing field. The forms in which basic materials are fabricated are also changing, for example, wood is finding new uses as plyboard and as processed wood shavings for insulation. Synthetic plastics are frequently mentioned as having striking possibilities in house construction (as in many other industries) but thus far have been little used, largely because of their present prohibitive cost. These developments in materials have frequently improved the quality of houses but thus far have not conspicuously changed the costs or the prevailing methods of house construction.

Some changes in technical methods to be sure have been made. For example, power tools such as electric and gasoline saws (both hand and stationary), concrete mixers, and pneumatic paint applicators have been increasingly used. In addition to these there have been developed a number of changes in methods of fabrication and assembly such as ready-cut houses using wood and more recently steel as the principal structural material. The members of these houses, studding, beams, wall plates, roof beams, rafters and trusses, floor slabs, and wall coverings are accurately cut and fabricated to designed dimensions in a mill or shop and then shipped to the site ready for installation. In some cases these methods appear to have effected substantial economies and in others to have provided houses superior in strength and durability to those built by other methods.

Within the past 3 years shop-fabricated houses using steel members for the structural frame; a wide variety of other materials; lumber, cement, stucco, gypsum, asbestos-cement, treated wood-fiber products, plyboard, aluminum foil, rock wool, etc., for interior and exterior walls and for insulation; and the usual materials for floor coverings, have been placed upon the market. One such house having a floor area under roof of about 900 square feet and including two bedrooms, bath, living room, kitchen, and utility room but without basement, is currently offered for about $4,200 delivered and installed. This includes complete automatic, oil-heating system, winter air conditioning, forced-draft ventilation, kitchen cabinets, satisfactory closet space, insulation, and other features.

Another type of shop fabrication provides wall, floor, and ceiling sections entirely from steel sheets. The wall units consist of sheet steel on both interior and exterior faces, welded to vertical channel sections (also of sheet steel) spaced at frequent intervals. These sections are of several standard widths up to 4 feet and are one or two stories in height. The insulation for exterior wall sections is installed by some manufacturers at the factory, by others after erection of the panels. Floor and ceiling units are fabricated in somewhat the same form as those used in the walls, the sections, however, being considerably deeper and much narrower. This method of construction provides only the structural shell, foundation, walls, floors, and roof, which are estimated to represent about one-fourth to one-third of the total cost of a house using this form of construction.

Shop fabrication of structural members using various materials is likely to be further extended during the next few years with some important effects upon costs, quality of construction, and architectural design. It may not, however, be the ultimate technical development in the fabrication and construction of houses.

The most alluring as well as bewildering aspect of modern housing from the structural point of view is the shop fabrication of complete panels. Comparisons with the automobile and other highly mechanized industries suggest many attractive possibilities to the end of substantial reductions in costs and far reaching improvements in quality. During the year 1936 complete houses fabricated in this manner were placed upon the market. One manufacturer offers a five-room house including two bedrooms plus a utility room but without basement, all completely insulated and provided with automatic oil-burning furnace, conditioned hot air, forced ventilation, kitchen cabinets, and generous closet space completely erected and ready for occupancy at slightly under $3,300, excluding a lot. The floor area under roof of this particular house is 860 square feet. The shipping weight complete with

fixtures is about 20 tons. The panels which are completely shop fabricated to the extent which local building, plumbing, and electrical codes permit consist of a welded steel frame approximately 8 by 9 feet to which are attached the wall sections and electrical fixtures, switches, and outlets. Insulation in exterior walls is installed as a part of the shop assembly. Door frames and doors, window frames and windows are also installed in the panels at the factory; painting and glazing only remain to be done after erection of the panels. The floor of these houses is supported by a steel deck, shop fabricated to dimensions.

Factors Influencing Shop Fabrication of Houses

Technically the methods which are now used by the manufacturers of shop fabricated panels appear to possess wide opportunities for improvement with consequent reductions in manufacturing costs. In several respects, however, such improvements although technically possible cannot be effected under existing building codes and regulations of building-trades unions. Any forecast of the extent to which a new housing industry may evolve from the present beginnings would be subject to many uncertainties. It is believed, however, that such a development will be largely influenced by the following factors:

1. The extent to which shop inspection of electrical, plumbing, and structural fixtures may be accepted in lieu of the job site inspection required under present codes.

2. The extent to which the cooperation of local building workers may be secured in the installation of factory-built panels, electrical, plumbing, heating, and ventilating fixtures.

3. The extent to which local dealers and contractors may be willing to market and erect such houses.

4. The extent to which the public may be willing to sacrifice present styles of exterior form and ornamentation in houses for increased comfort of interiors, less expense, and greater flexibility in subsequent additions or other changes.

5. The ability and willingness of manufacturers and dealers to finance the ownership of such houses until their acceptance becomes more widespread than it is at present.

Some types of flat-roofed houses made both of complete shop-fabricated panels or of prefabricated smaller units may be changed in plan, windows or doors changed in position or rooms may be added at only slightly more expense than would have been required at the time of original construction. In addition to this flexibility, some manufacturers contemplate the possibility of complete removal of such houses later to other locations to make way for models of improved design and facilities. Such complete mobility even though technically possible (which is not yet assured) would not appear likely except from neighborhoods which themselves had been free from social obsolescence or blight and which had maintained their original desirability as residential areas. If such a development should materialize it would, of course, tend to stabilize residence and to reduce the intracity migration to more and more removed suburban areas which has been very large in American cities for many years.

Problems of manufacturing organization and the perfection of line assembly for the extensive shop fabrication of houses are neither simple nor have they to any appreciable extent been solved. It is hardly likely, however, that such considerations will determine the success or failure of the completely prefabricated house to expand into a major industry in this country. On the other hand, it is almost certain that such consideration as those mentioned above as well as the highly fluctuating character of the housing demand will determine the trends in this new industry.

The trailer house is a novel development for which astonishing future claims are made. It has been stated by one writer that within 30 years half of the homes of the country will be mobile, by another that within 20 years more than half of the population of the United States will be living in automobile trailers. It is possible that this mode of living may be increasingly used by migratory workers. It may also be widely used during vacation periods by many families. For sustained use as a means of permanent domestic shelter, however, a 6- by 18-foot trailer house, having about the floor space of a single small room of a fixed dwelling, without adequate provision for utilities such as sewage disposal, and water supply for bathing and laundry purposes, does not appear likely as a permanent, normal mode of living for typical American families in any large number. Furthermore, any considerable increase of this character would most likely result in the levying of taxes upon trailers adequate to provide for streets, roads, schools, parking spaces, fire, sanitary, police, and other municipal services from which taxes this mode of living is now in major part exempt.

Integrated Neighborhoods

A housing trend in quite the opposite direction which has become increasingly important during the past few years is the design and construction of substantial neighborhoods as integral units with suitable amenities for comfortable living such as space and outlook, parks, and community centers as well as adequate schools and utility services. The economic advantages of such planned and regulated neighborhoods are also important. They permit some control

of obsolescence, lower cost of construction, lower capital outlays for utility distribution systems in areas which are not already supplied, and lower costs for providing such municipal services as fire and police protection.

Integrated neighborhoods of this character are believed to be most satisfactory in units providing for 3,000 to 6,000 persons, determined in part by the economical size of a primary school. Such neighborhoods have been designed and built by Government agencies and cooperative groups, as well as by strictly private developers. They have also been built both in large cities and in the outskirts of urban areas although the problems of land acquisition in the centers of many cities have proven particularly difficult. The salutary effects of integrated neighborhoods upon health, morals, and community solidarity are undoubtedly very large and such units are believed to offer much promise for the economic and well ordered social development of housing in the United States in the future.

Increasing urbanization in the United States was accompanied from 1925 to 1929 by a very active period of apartment-house construction. During this period the total number of multifamily dwellings in cities of 25,000 or more in the United States was substantially greater than the number of single family houses. During the depression years such residential construction as took place was predominately one- and two-family dwellings. Improved transportation by subways, express highways, extensive vehicular tunnels, and bridges, together with the readily available mechanical devices for heating and for housekeeping may somewhat offset the trend toward apartment-house living, which would normally be expected with returning urbanization.

Urban Modernization

Physical depreciation and obsolescence of dwellings, although in most cases gradual, are becoming increasingly important in their social and economic effects. They have already created major public problems in many American cities. The common practice by which the occupants of older dwellings have vacated such units (frequently in perfectly sound structures) for the use of families of lower income has proceeded to the point where many old units, wholly inadequate, unsafe and unsanitary, according to any acceptable modern standard, are sparsely occupied or completely abandoned. Many of these properties are actual liabilities both to their owners and to the governmental jurisdiction in which they are situated. The land in such areas is, nevertheless, frequently held at high speculative values. This is due in part to an absence of adequate zoning restrictions. Moreover, under present laws relating to the ownership of real property, which for the most part is held in comparatively small lots, the replacement of those submarginal structures by improved residential buildings is quite unprofitable. Consequently, in nearly all States there is needed adequate legislation permitting the consolidation of urban land, either by collective action of the present owners, by granting the right of eminent domain to public utility housing corporations or by the exercise of existing legal powers by municipal and State governments. In brief, one of the major economic and social problems of American cities is the rebuilding of areas on which submarginal structures predominate, or the removal of such structures and the dedication of the land to parks and playgrounds in order that it may serve a useful public purpose.

Social and Economic Aspects of Technological Trends in Housing

Technical changes, as have already been observed, influence home building through their effect upon costs and through their contribution to the comforts and conveniences provided in dwelling units. They seldom dominate the volume of residential building, however, to the extent that similar changes have been responsible for the expansion of such industries as the manufacturing of radios and automobiles and (to a striking degree during the depression years) of many chemical products.

Conversely, social and economic factors such as the fluctuations in the demand for dwellings and the types and practices of financial institutions are important in determining the trends in technological development. During the 9 years from 1926 to 1934, residential-building activity was steadily declining in what appears to be a recurring long-time cyclical fluctuation which has characterized the building industry for many years. Data on residential building separate from other types of building are not available in any satisfactory form much earlier than for the year 1915. However, for building as a whole (which is from 40 to 60 percent residential as reported by permits granted) studies by Mr. John R. Riggleman, senior highway engineering economist of the United States Bureau of Public Roads, and others, indicate that these fluctuations in activity of 18 to 20 years in duration have been experienced since at least 1830.[5] The causes of these fluctuations are not well known but appear to be related to vacancies and rents, interest rates, and construction costs, and more remotely, but

[5] For a part of this period, 1875 to 1932, Mr. Riggleman's studies are summarized in the Journal of the American Statistical Association for June 1933, vol. XXVIII, pp. 174–183. Further unpublished investigations which Mr. Riggleman has very kindly made available, indicate that similar fluctuations occurred in earlier years at least as far back as 1830.

nevertheless fundamentally, to changes in marriages and migration and to a certain elusive inclination or disinclination to commit money and borrowings over long periods of time.

The long-time trends in population in the United States have been characterized in the past by an upward arithmetic increase but a declining rate. Superimposed upon this long-time trend have been large fluctuations in the arithmetic increase each year (based upon annual estimates since 1890) as well as striking fluctuations in internal migration, particularly from farm to urban areas. Since 1924 there has been a sharp and, with the exception of 1 or 2 years, sustained decline in the annual net population increment up to and including 1933. This decline had resulted both from a lower number of births over deaths and from a decrease in net immigration over emigration which was actually negative for 3 years. These changes in population have been accompanied by changes in marriages which were declining for several years; 1934, 1935, and 1936, however, showed marked increases over 1933. If past experience may be taken as a guide, a considerable part of the "marriage deficit" may be liquidated very rapidly and the population and total number of families added each year may be expected to show a considerable increase during the next few years.

In times of naturally declining demand, conditions are not favorable to the introduction of highly developed technical methods, particularly in housing and other building construction. The low levels of cost which must be attained by contractors, builders, and others in such periods in order to sell their product in competition with standing structures, are distinctly unfavorable to new construction in any form. At the present time in the United States, however, the demand for housing is rapidly increasing, and conditions are much more favorable to investment in residential property than they have been for many years. Rents have been increasing since January 1934, and vacancies in dwellings have declined from approximately 8 to 10 percent in 1932 to 2 to 3 percent in the fall of 1936 in such cities as Denver, Cleveland, and St. Louis, for which accurate data are available. The prospective need during the next 8 or 10 years in terms of the new dwelling units which will be required in urban and rural nonfarm areas in the United States is variously estimated to average from 500,000 to 800,000 units annually. The corresponding number actually built in 1934 was only slightly more than 60,000 units, and in 1936 approximately 275,000 units. A period of gradually increasing activity appears likely for the next 8 or 9 years during which the volume in some years may very likely equal or exceed the 1925 level of 900,000 units. Market conditions such as those in prospect at least for the next few years are thus more favorable to the development of new technical processes in the design and construction of houses than they have been for many years.

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Large Buildings [6]

The types of building which are considered in this section are those built primarily for the purpose of enclosing sheltered space for commercial and manufacturing purposes. Such structures are largely influenced by economic considerations such as the costs of construction, interest rates, and land values as well as by such social factors as the movement of population and traffic flow in given areas.

The introduction of steel and of reinforced concrete during the past 50 years has greatly influenced the height and to some extent the economy of construction (particularly the structural frame) of large buildings. The general architectural treatment and the methods of construction of exterior walls, interior partitions, and floors have changed more slowly. Rigid, seldom revised building codes, as well as aesthetic conservatism, have tended to retard changes in this direction. The skeleton frame of a tall building, even one covering a considerable area, may often go up quite rapidly, perhaps a story a day. This is made possible by the use of structural parts which are carefully fabricated in a shop ready for quick installation. The walls, floors, and partitions (which in the case of steel construction are actually hung onto the structural frame) have been in the past largely fabricated on the site from elementary materials and have required a rather long period of time for their completion. Architects, engineers, and manufacturers are giving a great deal of attention at the present time to possible methods of fabrication of walls and other structural members, particularly for commercial office buildings. The increasing development of such methods of prefabrication has a tendency to reduce the number of workers required on the site at the time of construction, but to increase employment in the manufacture of these materials, in many cases under conditions more favorable to safety and sustained employment than would be possible on the construction site.

In commercial building the tendency today is away from the construction of very tall structures which often are expensive at great heights both from the point of view of construction costs as well as from the point of view of the elevator space required to service such buildings. The trend is toward the development of unified commercial districts and single structures covering several city blocks such as Rocke-

[6] Prepared with the assistance of Harvey Wiley Corbett, Fellow American Institute of Architects, New York, N. Y.

feller Center in New York and the Merchandise Mart in Chicago. From the economic point of view, such developments appear very promising but are nevertheless greatly retarded by the difficulties encountered in the consolidation of land ownership which frequently in large urban areas is in the hands of many small property owners. The development of Rockefeller Center in New York City was greatly facilitated by the fact that the land on which it is built was obtained for the most part as a leasehold from Columbia University.

The construction of tall buildings has in the past in the United States introduced a highly speculative element into land values. This problem is most acute in New York City. The zoning for use and height developed there about 20 years ago has been in large measure the basis for similar restrictions in other cities. Improvements in the restrictions upon various land uses and the height and mass of buildings which may be erected in given areas are likely to be made in the future and are actually under consideration by civic organizations of the New York metropolitan area. Contemplated changes in zoning restrictions in the light of recent experience will have a tendency to stabilize land values and to result in other salutary effects.

In the design and construction of manufacturing buildings much more attention is now being given than formerly to the comfort, safety, and convenience of the workers as well as to the careful arrangement of production stages in order to develop a high efficiency in the whole manufacturing process. Mechanical conveyors and other transportation equipment are increasingly used. Improvements of the last 15 years in trucks and highways have, to an important degree, been responsible for the establishment of many new factories on the outskirts of metropolitan areas. This has resulted in a substantial amount of new factory building in which a great deal of attention has been given to planning and design of the manufacturing plant as an operating unit rather than as a group of industrial shops.

Both improved transportation and communication have tended to reduce the concentration of manufacturing and commercial activity in restricted areas. Also the prevailing tendency is toward the concentration of such activity not in one or two cities in the United States but in a number of such areas throughout the country. The structures themselves may also in the future be less massive and more flexible particularly with regard to exterior walls and partitions. The use of shop-fabricated interlocking units, for example, would provide greater opportunity for growth and greater elasticity of plan arrangements for changing process of manufacture or commercial office use than are readily possible under prevailing methods of construction. Furthermore, instead of isolated tall buildings, we may expect to see the development of an increasing number of unified commercial and manufacturing areas.

Foundations [7]

Foundation engineering has experienced one of its greatest periods of advancement during the past decade. In this period the science of soil mechanics has come into being, and its rapid development has marked the transition of foundation engineering for clay soils from an art to a science. No longer is it necessary or considered good practice to base a soft-ground foundation design entirely on experienced judgment and precedented action of similar soils. In dealing with clays and other cohesive soils it is now the foundation engineer's duty to subject undisturbed samples of such soils which affect his design to careful laboratory analyses and tests. Through soil analyses he determines the effect and soil action under various intensities of load, the shearing strength, rate of consolidation, and water content of the soil, and predicates his design on determined soil factors and on the anticipation of definite soil reactions. Notable progress has also been made in caisson design and construction. These developments have greatly enlarged the conditions under which many works and structures may be technically and economically feasible.

Building foundations during the past 10 to 20 years have seen an important advancement in the economy of installations. Expensive pneumatic caisson and cofferdam installations have been replaced by open piers and open cofferdams made safely possible through the use of new methods of installation and by improving pumping of and sealing against ground water. Several types of cylinders have been developed which may be sunk to bedrock through considerable depths of overlying water-bearing materials where previously pneumatic installation would have been required.

A new principle of building foundation design has recently developed to resist or control settlements in soft grounds through the incorporation of the substructure into a form of stiffening girders, trusses, or trusses without diagonals, i. e., Vierendell trusses, and through the principle of removing a soil weight comparable with the weight of the building. This principle was among the first practical applications of the theories of soil mechanics and may well permit the utilization of soft ground areas which formerly were unsuited or uneconomical for the support of large structures.

[7] Prepared by Carlton S. Proctor, consulting engineer, New York, N. Y.

In the field of bridge foundations, the special development of the Moran caisson to meet the totally unprecedented foundation conditions in the West Bay Crossing for the San Francisco-Oakland Bay Bridge constitutes a revolutionary departure from precedent and makes technically and economically feasible bridge locations heretofore uneconomical or impracticable. At the San Francisco-Oakland Bay Bridge the depth of open water and the depth of required sinking for the bridge pier caissons to reach rock, a maximum of 240 feet, considerably exceeded any previous bridge pier installation. The Moran caisson which was developed for this purpose consists of a cellular caisson with pneumatic flotation, providing the equivalent of a false bottom near the bottom of each dredging well, but in which the false bottoms can be moved at will upward or downward within the dredging wells and completely removed preparatory to open dredging of the caisson. This is accomplished by constructing the dredging wells as circular steel cylinders, which are extended well above the top of each caisson and are covered by steel domes fitted with valves and connections for the introduction of compressed air and for the later introduction of water as the compressed air is vented off.

The piers of the Mississippi River Bridge at New Orleans further illustrate recent developments in the placing of bridge foundations at great depth. A maximum depth of 90 feet of open water to a shifting semifluid silt bottom, required a light caisson to provide flotation and to minimize the pressure upon the stratum of compact sand which supports the structure. But opposing these requirements for maximum lightness was the necessity of providing sufficient weight to overcome the skin-frictional resistance encountered in sinking through alternate sand, clay, gumbo, compacted sand, and more gumbo to the then (1934) unprecedented depth of 185 feet. This problem was met by a new type of caisson design which eliminated the usual thick, heavy outer-wall construction and provided that certain portions of the caisson walls should be unfilled above the height required for the caisson seal. These hollow spaces not required for permanent construction were temporarily filled during caisson sinking with ballast which was subsequently removed when the caisson was landed.

The progress of caisson construction indicated by the above examples has substantially enlarged the technical possibilities for bridges and other structures over water of considerable depth. Advances in the methods of providing support for large buildings and in greatly reducing costs of such work have also been conspicuous. The ultimate consequences of this progress are not altogether clear; many other technical and economic factors are also involved. It will, however, undoubtedly have important effects upon the magnitude of structures and the wider range of conditions under which they may be built as well as upon the number of projects which, in the light of reduced costs, may be considered practicable.

Bridges [8]

Recent years have witnessed a great advance in the science of bridge construction. This has been due to a number of factors; namely, the development of materials, especially alloys and lightweight metals, refinements in design arising from a better understanding of the theory of structures aided by research and experimental work, and improvements in fabrication and construction methods and equipment. Certainly our modern bridge structures owe their existence to the technical developments which have taken place.

When viewed for the period of the last 100 years, the modern period of bridge construction, progress has been truly phenomenal. Although adhering to the same fundamental types of earlier times, spans have been increased over sevenfold and span weights, capacity of erection equipment, and speed of construction have been increased a hundredfold.

Materials

Perhaps the most important factor which has contributed to progress in bridge construction in recent years has been the development to a marvelous degree of the strength and excellence and the economical mass production of the two artificial materials which now predominate in the field of bridge construction, steel and portland cement concrete.

Alloy and other high-grade steels, by their greater strength and corresponding saving in weight of metal, are essentials in important modern bridge structures. Wire for the cables of suspension bridges has also been increased in strength to a marked degree—from a wrought-iron wire having an ultimate strength of 60,000 pounds per square inch to the present cold-drawn steel wire of 235,000 pounds. The last-named material makes possible great suspension bridges, such as the 3,500-foot span of the George Washington Bridge and the 4,200-foot span of the Golden Gate Bridge.

The possibilities inherent in lightweight metals are becoming continually more apparent. For example, aluminum has been proposed in a number of cases where it is desired to replace an existing floor system with one of greater capacity without adding to the total weight of the structure, as in the case of the Brooklyn Bridge.

[8] Prepared by O. H. Ammann, Chief Engineer, and E. W. Bowden, Assistant to Chief Engineer, the Port of New York Authority.

Portland cement concrete has been growing in importance as a bridge construction material since metal reinforcement embedded in concrete was introduced in France in the 1880's and a few years later in this country. A marked improvement in this material has been made in the last few years due to a better understanding of the methods of mixing and placing. The compressive strength of concrete ordinarily incorporated in present-day structures exceeds that of 25 years ago by at least 50 percent.

Design

The theory of structures is also now better understood than formerly because of a greater knowledge of the properties of the materials, brought about by extensive research and experiments, calculations of stresses having been repeatedly checked by measurements on actual models or on members of structures as actually built. Stresses in the George Washington Bridge towers, the Golden Gate Bridge towers, and the Bayonne arch were checked by means of models, while both model readings and calculations were checked on the George Washington and Bayonne Bridges by stress measurements made under actual field conditions.

Similarly a better understanding of the action of stresses in reinforced concrete arches has made possible relatively greater increases in span lengths, the maximum of which in this country is the 460-foot span of the George Westinghouse Bridge in Pittsburgh completed in 1932. Another instance of improvement in bridge design has to do with the development of the rigid-frame bridge, a type which has effected great economies in bridges of relatively short spans of from 80 to 120 feet. Here again the theory has been developed on the basis of laboratory research by such methods as photoelastic analysis and the studies of models.

Construction Methods

An important factor in bridge construction has been the development of high-power fabricating machinery, equipment, and methods. Today the fabricating shops, equipped with power-operated punches, drills, shears, planers, and riveters, turn out completely assembled members weighing as much as 150 tons. A comparatively short time ago practically all fabricating was done at the bridge site. Of equal importance has been the development of erection equipment of increased capacity. Tractor cranes now have capacities up to 40 tons and certain sections of the Triborough Bridge viaducts were erected entirely by such cranes. In many cases the design of the structure takes into account the type of equipment to be used in erection, as was the case on the San Francisco-Oakland Bay Bridge and the Golden Gate Bridge, where a hammerhead crane, mounted inside the column sections, was used for tower erection.

Welding has played an increasingly important part in steel construction both in the fabricating shops and in the field. This important technique has made most of its development within the last 15 years. Savings in properly designed welded trusses are said to run as much as 30 percent under the cost of riveted structures. Cable spinning, stepped up to unprecedented speeds on both the San Francisco-Oakland Bay and the Golden Gate Bridges by the use of multiple spinning equipment, is another example of the possibilities of modern equipment.

Other important improvements in construction equipment have had to do with the handling and placing of concrete. Belt conveyors for aggregates expedited construction of the anchorages of the George Washington Bridge. Trucks equipped to mix concrete in transit, pumps for placing concrete at points difficult of access, vibrators for securing dense concrete, and mechanical screeds for securing a high degree of perfection in the finished surface, have all played an important part in the construction of the Triborough Bridge, as, in fact, they have in many modern structures. Pumping concrete, in particular, is a distinctly modern innovation. First introduced on a commercial basis in 1932, this method of placing now accounts for over 1,000,000 cubic yards per year.

Economic Considerations

A large bridge structure depends for its construction upon justification from a self-liquidating standpoint. The time necessary for construction therefore becomes a very essential feature for two main reasons. The first of these is that the contractor carries an overhead expense of from 15 to 25 percent, which runs as long as he is on the job and which is directly saved by any means that will expedite the progress of the work. Secondly, interest paid for construction funds must be kept at a minimum since this is an important item in the total cost of the project, and in the case of a large structure, such as the Triborough Bridge, where the funds borrowed may total as much as $35,000,000, may amount to over $100,000 per month.

The improvements in construction equipment which make possible the reduction of construction time to a minimum are therefore exceedingly important, and remarkable progress has been made along these lines. For example, the Eads Bridge at St. Louis, completed in 1874, was erected at the rate of about 90 tons of steel per month, but the Bayonne arch, completed in 1931, was erected at the rate of 1,800 tons per month. In order to be able to compete at all, the present-day

contractor is obliged to make the maximum use of the most modern material-handling equipment available.

Thus improvements in materials and design methods have contributed materially to modern bridge construction. But most important of all, the development of highly mechanized equipment by greatly increasing the speed of construction, has made more projects economically feasible and thus has been the principal factor resulting in the employment of labor in this branch of the construction industry. At the same time the manufacture of essential equipment has also offered new opportunities for the employment of labor.

The construction of large bridges, especially those over wide streams traversing great metropolitan centers, such as New York, Philadelphia, Pittsburgh and San Francisco, has a pronounced influence upon the economic life of the communities they serve. Not only do they effect enormous savings in cost and time to the traveling public, but they are also of vast indirect benefit to the public in permitting the spreading of the population to comparatively undeveloped areas, in improving the accessibility of the countryside for recreation to those who live in the congested centers, and in bringing the commercial and educational institutions of the city closer to the people living in the surrounding country.

Tunnels and Subways [9]

For many years the construction of tunnels in the United States was principally identified with railroad work in mountainous areas. More recently, tunnels have been widely used in providing for the flow of large quantities of water for hydroelectric-power development, for irrigation, and for urban water supply upon a greatly extended scale. Tunnels are also in wide use today for sewer lines and for the carrying of gas, power, light, and other utilities. They have also been extensively used in rapid transit systems and more recently for vehicular traffic in New York, Detroit, Oakland, Boston, Liverpool, Antwerp, and other cities. The social effects of these structures, particularly in facilitating the growth of metropolitan areas, are very large.

Tunneling, as is also true of nearly every human endeavor, has undergone a constant change since its inception. The ancients drove tunnels by building fires against the rock face followed by throwing water on the heated surface, the sudden change in temperature causing the rock to split and spall. For centuries, fundamental advances in tunneling were few, but since the turn of the century, and especially in the last decade or so, the art of tunneling has advanced amazingly, due primarily to the rapid development of equipment and materials. While the fundamental changes have been few, they have had a tremendous influence in the development of tunnel driving, which in turn has had important social and economic effects.

First came the use of hand-driven iron or steel drills which, coupled with the development of explosives, provided means for drilling and blasting of the rock. To be sure, hand drilling was slow and tedious; but with cheap and husky labor, tunneling became an economic possibility.

The next significant advance, probably the greatest in all tunneling history, was the invention of the power rock drill. Although invented in 1849, the power drill was not used to any extent until 1867, when it was adopted for driving the famous Hoosac railroad tunnel through the Berkshire Mountains of Massachusetts. Naturally, the first mechanical drills were crude and clumsy, and were powered by steam. Today, the modern rock drill, compressed-air operated, is a precision tool, highly efficient and effective. The advent of the power drill was the first mechanization of tunnel-driving procedure. It changed the whole concept of tunneling, and demanded for the first time the use of skilled or semiskilled workmen. Thus was opened a new field or endeavor for the mechanic and the skilled tradesman. From a social and economic standpoint, the mechanical drill reduced the cost of tunneling and speeded up the work tremendously, thereby greatly widening the possible use of tunnels. The interest alone saved in faster construction made many projects economically feasible which otherwise would have been too costly.

The next great advance in tunneling was the adoption of compressed air as a means of driving subaqueous bores and those through soft, or extremely wet ground. Compressed air was introduced about 75 years ago, and some 25 years later the development of shields for use in compressed-air tunnels perfected a tunneling process that has contributed much, particularly to urban community growth. Using these methods it became possible to burrow under rivers, bays, and through soft, wet ground. The range and use of tunnels was thus greatly extended. A shield is essentially a huge, open-ended cylinder of cast iron and steel, sometimes bulkheaded at the face, which is shoved ahead into the mud by powerful hydraulic jacks bearing against the tunnel lining already erected within the protection of the shield. The compressed air within the tunnel aids in supporting the soft walls and keeps the bore free of water. Without the compressed-air and shield method, we would not have such important and useful tunnels as the Holland (New York City), Boston and Antwerp vehicular tubes, the Pennsylvania Railroad and Hudson & Man-

[9] Prepared by H. W. Richardson, Associate Editor, Engineering News-Record. Valuable information was also supplied by R. F. Schaefer, Assistant Engineer, the Port of New York Authority.

hattan Rapid Transit bores under the Hudson at New York, or the New York subway crossings under the East River. The significance of this advance in tunneling upon the growth of the New York metropolitan area is apparent.

The last major advance in tunneling operations was the introduction of mechanical mucking machines. Formerly all spoil, or muck, was loaded into cars by hand for removal. However, this means of getting rid of the excavated or blasted muck was far out of step with rapid drilling methods. The time cycle of drilling, loading, blasting, and mucking out was greatly unbalanced. Therefore, it was inevitable that mechanical means would be developed for muck removal. Mucking machines are essentially power shovels, those of large sizes resembling the common excavating shovel, but the smaller machines have a distinctive form of their own to meet limited clearances in small tunnels. All mucking machines are either electric or compressed-air powered.

These are the major tunneling developments, and are all of fundamental importance. Yet it is the introduction of scores of mechanical devices and pieces of equipment that makes tunneling the highly mechanized, scientific procedure that it is today: Drill carriages for the mounting of the rock drills as a time-saver in setting up and dismantling of drilling equipment; the electric locomotive, offering fast haulage for muck and materials; the collapsible steel form, which, with the development of the concrete placing machine or "gun", has revolutionized concrete-lining procedure; the pressed-steel liner plates that have made soft-ground tunneling so much safer, easier, and less expensive; the improvements in explosives, now available in safe form for any type of ground encountered; the use of electric detonators, which has made blasting safe and certain; and mechanical ventilation for safeguarding the health and comfort of underground workers. Modern tunneling, being largely mechanized, requires skilled workmen and technical organization. It thus not only provides needed and useful engineering work, but offers considerable employment to a highly specialized class of workmen.

Subways

Subway building is a specialized form of construction and its problems are different from any other class of work. As is the case in tunnel work, it has developed and improved along mechanical lines. Except where subways lie in tunnels, their construction is of the cut-and-cover type of work wherein a trench is excavated, the line structure built, and the trench backfilled to its original state. As this usually takes place in busy city streets, the difficulties involved are many and serious. Subway building requires skilled workers, experienced in that class of work. This type of construction is of tremendous social importance in the three American cities in which such structures have been built, but because of the very limited local application, they do not have the wide interest and importance attached to other types of structures.

Social and Economic Factors

Tunnels during the past few years have had an increasingly important place in the rate of growth and type of development of metropolitan areas. They have been essential parts of systems for conducting pure water from remote watersheds to such areas as Boston, New York, and Los Angeles. They have also made possible many hydroelectric developments which otherwise would not have been practicable. Underground rapid transit has substantially determined the character of commercial activity especially in New York City. Street-level traffic even under present conditions is at times extremely congested. Tunnels and bridges (discussed in the preceding section) have resulted in a substantial migration of population from Manhattan to other boroughs in New York City, particularly the Queens and the Bronx. Vehicular tunnels in New York, Detroit, Boston, and other cities have also greatly enlarged the reach of day-to-day commercial activity.

Tunnels and bridges in urban areas frequently serve much the same purpose and it is at times difficult to determine which type of structure will serve most satisfactorily and economically. Developments within the past 5 to 10 years have tended to make both types possible at lower cost and under a much wider range of conditions. This fact, combined with the trend toward a widening range of social and commercial activity within metropolitan areas, may very likely sustain both bridge and tunnel construction at present levels for a number of years.

Dams[10]

The adaptation of machines to particular purposes by increasing their size, portability, and strength, as well as the devising of new appliances, is strikingly evident in the present construction of large dams. Boulder Dam, on the Colorado River in Nevada and Arizona, a concrete arch, gravity type, has recently been completed to its height of 727 feet. Grand Coulee on the Columbia River in Washington, a concrete straight gravity type, will be 4,200 feet in length and will contain approximately 10,500,000 cubic yards of concrete, when finished. Conchas Dam, on the Republican River in New Mexico, consisting of a concrete center section with earthen wings, will have a crest

[10] Prepared by John C. Page, Commissioner, U. S. Bureau of Reclamation.

length of 26,000 feet—practically 5 miles. Fort Peck, on the Missouri River in Montana, a hydraulic earth fill, will contain the largest volume of all dams—100,000,000 cubic yards—and its thickness at the base will be more than one-half mile.

Starting with investigations and designs, continuing through the preparatory stages of construction, the securing of materials, and ultimate construction, there is found a tremendous advance in the last several years in the details of investigational procedure, the theoretical considerations in design, the adequacy of preparatory features, the excellence and strength of materials, and the efficient methods of actual construction; all directly concerned with the expanding use of the machine.

To mention only a few examples, drill cores 3 feet in diameter are now secured in the drilling of dam foundations, providing not only excellent samples but, also, allowing actual visual examination of the substructure from the drilled hole.

In the field of design, models to test hydraulic flow and pressures are often constructed to a scale of 20 to 1. Models of dams are built of hard rubber, aluminum, and other substances. Mercury is used to secure the hydraulic load, and the deformations are measured directly. Determination of stresses is also obtained by passing polarized light through translucent models of the structure or device to be built. A check on theoretical calculations is made by embedding electrical thermometers and strain meters in the dams, installing tilt meters in dam galleries, plumbing shafts by reflected light rays, and making exact surveys by transit, tape, and level. For earth structures, detailed laboratory studies are made of foundation and structural materials and the design is based upon recently developed principles of soil mechanics and soil chemistry.

Materials have kept in step with advanced methods in other activities. Metals have increased in strength, special alloys are provided for particular purposes, and low-heat, slow-setting, and quick-setting cements are all available. Motive equipment has gained in strength, power, and portability.

In construction, excavations for the structures have involved the use of 16-cubic yard trucks, 20-cubic yard wagons hauled by 60-horsepower tractors, and 60-inch belt conveyors capable of moving 100,000 tons of earth and rock in 24 hours.

Sand, gravel, and cobbles for the concrete structures are classified by immense 800 ton-per-hour screening plants. Cement, much of it of special low heat characteristics, is shipped in bulk to the mixing plant and transferred to the plant silos by specially designed compressed air pumps. Sand, gravel, cobbles, cement, and water are each automatically weighed and passed to a battery of four to six mixers of 4 cubic yards capacity, dumped into buckets of 4 or 8 cubic yards capacity, and transported by transit mixer trucks, electric or gasoline trains, movable tower cableways, gigantic traveling cranes, or long-boom derricks to the pouring site. As much as 2 million yards of concrete are placed in a single structure in 1 year, and month after month 200 carloads of materials are placed in the dam each day.

The tremendous volume of concrete in a relatively small space introduces problems of temperature stresses. For example, at Boulder Dam, 150 years or more would have been required, by natural cooling, for the temperature of the concrete to be reduced from that at hardening to that of the air, water, or other surrounding medium. During this time, cracking would have developed as a result of differential cooling. Pipes were, therefore, placed in the dam at approximately 5-foot intervals through which water was circulated at a temperature slightly above freezing, and the dam was thus cooled in a period of 20 months. The resulting openings between blocks, formed by the contraction from cooling, were filled with a water-cement mixture of grout.

Similar ingenuity and speed are manifest in the construction of earthen dams. At Fort Peck the four electrically operated dredges, each having a 28-inch discharge, place from 3½ to 4 million cubic yards of material each month at an average cost of approximately 25 cents per cubic yard. The cost of placing concrete in dams is approximately $4.75 per cubic yard.

It would have been impracticable from an economical standpoint, and almost impossible from a physical standpoint to have erected these structures without the aid of modern machinery, due primarily to the inaccessibility of site and the large volume of water flow. Presenting a concrete example, Boulder Dam and the Great Pyramid have practically identical volumes. According to historians, 100,000 men labored 20 years in the construction of the pyramid, while 1,200 men in less than 2 years built Boulder Dam. The pyramid thus required 2,000,000 man-years of direct labor and the dam, 2,400.

From a sociological point of view, the benefits accruing from the building of these dams are far reaching. Water and power resources have been conserved, effective barriers have been raised against flood and drought, homes and a means of livelihood have been provided, communities have been stabilized, and electrical energy has created industrial pay rolls and brought conveniences and comfort to millions of homes. In addition there are the immediate beneficial effects through aid in the solution of the unemployment problem. Thousands of men assisted in their creation, and it is estimated in the building of these large structures that

for every dollar spent in direct labor an additional 2 or 3 dollars were paid for the labor involved in manufacturing, marketing, and transporting materials and machinery.

Water Supply [11]

Construction for the procurement, extention, and betterment of water supplies and distribution works in the United States has a normal annual dollar volume at present prices of about $150.000,000 or a little more than $1.15 per capita per year. It is obviously a large field which is increasing in importance with the trend in consolidation of farm operations and the continued long-time growth of urban centers of industrial activity. There were only 17 waterworks in the United States 136 years ago, all but one of which were privately initiated, constructed, and owned. Twelve years ago there were 9,850 waterworks, only 30 percent of which remained in private ownership. The established trend in public ownership of waterworks has continued at an accelerated rate in recent years. Today there are probably no less than 50,000 employees engaged in operating waterworks and possibly three times this number on the average are employed in the manufacture and transportation of waterworks materials, equipment, and supplies, and in building new works and extensions and betterments of existing works.

Two-thirds of a century has elapsed since the construction of the first filters for a municipal water supply to be built in the United States at Poughkeepsie, N. Y., in 1870, but general appreciation of the importance of pure water supplies in promotion of health and protection of property has developed within the present century. Chlorination of water supplies did not begin until 1908 and the first standard for drinking water for use in interstate commerce issued by the Public Health Service of the United States Treasury Department did not appear until 1914. By 1919 State divisions of sanitary engineering had been established in 43 States most of them having power to pass upon plans for waterworks improvements. In a group of 20 large cities with typhoid death rates in 1900 ranging from 13 to 144 per 100,000, such death rates were reduced by 1920 to a range of from 1.1 to 7.4 per 100,000. Technological development of waterworks has taken place almost entirely in the present century following the demonstrations of a vanguard of workers at the Lawrence Experiment Station established by the Massachusetts State Board of Health in 1887 and the Louisville Experiment Stations where the problem of clarifying turbid river waters for municipal supply was studied in 1896.

[11] Prepared by Malcolm Pirnie, consulting engineer, New York, N. Y.

Technology in water supply in large measure has been adapted from processes, equipment, and materials borrowed from highly competitive private industry. Because of lack of competition in most local businesses of supplying water, acceptance of new processes, more efficient equipment, better materials, and improved methods of construction has lagged far behind their universal use by private industry. Much of the progress that has been made has been energized by the efforts of volunteer organizations such as the American and the New England Water Works Associations and the American Society of Civil Engineers. Sanitary quality of water supplies has been materially improved by the efforts of State Boards of Health and through the growing desire of municipal officials to have the water supplies of their communities meet the Treasury Department standard. However, the full extent of technology available today in furnishing municipal water supplies cannot materialize in the present circumstances of rapidly changing water works personnel. Often a group of operators no sooner have mastered the rudiments of their jobs before they are replaced by another group, the result of change in the ruling political party. Disaster, although otherwise reported, has resulted in many instances from this cause.

Waterworks constructions involve buildings of the smaller type, foundations, bridges, tunnels, dredging and excavation, dams, and relocation of railroads and highways. They are job site operations to the extent of from one-third to two-thirds of their cost. About one-third of the total number develop surface water within the natural drains of the adjacent or contiguous lands, the other two-thirds tap the underground waters for relatively small supplies. In arid sections and in thickly populated areas supplies must be obtained from distances of as much as 100 miles or more, sometimes involving controversies and negotiations between two or more States.

Enlargement of Water Uses

Almost universally water is still regarded as a necessity which must be used sparingly. It is truly a commodity like grain, being an annual crop related to the rainfall and depending for its utilization upon storage provided in connection with the area which catches and produces it. Except in the most arid areas of the country, however, water is plentiful and cheap even when filtered and delivered under pressure to the consumers' premises. Cost of water for household use of the average small family does not vary greatly from the cost of morning and evening newspapers or a daily streetcar ride for the head of the house from his home to his work. When it is reflected that at least half of the investment in the average waterworks

is justified by the fire protection it affords, and that in a city of 100,000 population the cost of furnishing fire fighting capacity in the waterworks system is less than half the cost of maintaining the fire department required to use it, there can be no doubt that municipal water systems contribute as much per dollar of cost to the present standard of urban living as any other commodity or service. As a commodity water should be developed and sold in larger volume as one of the least expensive contributions to higher living standards. There exists a definite trend in this direction by its use in connection with refrigeration, air conditioning, and in swimming pools now being constructed in many communities to offer clean water bathing as an attractive and much more healthful alternate to the polluted waters of the neighborhood streams, ponds, and shores.

More than half of the value of all the waterworks in the country lies buried in the system of distribution pipes, valves, hydrants, meters, and other accessories amounting to a total of about 1½ billion dollars, the greater part of which is invested in cast-iron pipes. Before filtration was practiced, such pipes on the average lost about 23 percent in carrying capacity in the first 20 years of use, but since filtration has become widespread in water supplies this loss in carrying capacity has increased and even doubled in many instances. Comparable losses have been experienced in consumers' plumbing systems. Present technology in water treatment can prevent such appalling loss of value and even reduce to a substantial degree the prefiltration losses.

Skilled and well-trained personnel is essential in the management, design, and operation of nearly all waterworks systems. Consequently, the extent to which technical progress and other developments will be put to full public use in the future will be determined in an important degree by the extent to which waterworks are divorced from political spoils systems and the managers and operators are chosen solely from those best qualified by training and ability and continued in office so long as they are effective. State and Federal Governments can also aid by making adequate appropriations to their public health bureaus and by setting an example to local governments by long-term appointments of properly qualified men who would be authorized to cooperate in committee work of the national and State waterworks associations. Federal aid in the compilation of waterworks statistics could also lead eventually to a system of classification of water systems which would introduce a competitive incentive for improvements and betterments that is now lacking. There is no more fertile field for cooperative support of community services by Federal and State Governments.

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Sewage Treatment and Disposal [12]

Wherever water is found on the earth's surface it submerges the lowest of the surrounding lands forming brooks, rivers, ponds, and lakes which are the natural drains of all the lands sloping to them. Within such water there is a continual battle for existence between countless hosts of animal and vegetable life. If conditions are such as to maintain the delicate balance between the various forms of life the water is relatively pure and these life cycles are responsible for what is often referred to as self-purification of water in streams and lakes. A river polluted with sewage may be seen to improve in quality progressively down stream, but there is no insurance as often erroneously stated that pathogenic bacteria have been removed. However, certain of these life processes in water may be stimulated to varying degrees by artificial means.

Modern plumbing conveniences have promoted pollution of streams by depositing the human wastes of urban populations into 99 parts of pure water drawn from the waterworks system and conveying the mixture in drains to discharge into rivers, lakes, and tidal waters. This is known as disposal by dilution, but as sewage volumes have increased, the amount of dilution has decreased proportionately until many of our rivers, particularly in times of low stream flow, and large expanses of tidal and lake waters are dominated by the lowest forms of life and now contain organic matter in various stages of putrefaction. To augment this condition a new technology in the field of garbage disposal has recently been introduced. It is now possible to install a grinder in the kitchen which will convert all garbage into a fine pulp that is then mixed with more pure water and discharged to the sewers. Obviously, continuing increase in urban population and development of new conveniences between the waterworks and the sewers is placing a continually increasing load of pollution in adjacent waters.

There is no cheaper nor better way of disposing of sewage than by dilution if the proper amount of dilution can be obtained at all times. Storage reservoirs constructed on drainage areas to regulate stream flow for power purposes or to retard flood flows by holding back storm run-off to be released gradually during a subsequent period of weeks or months are of almost equal value in raising the dilution factor for the almost universal present method of disposal of urban sewage. Flood-retarding and stream-flow regulation works therefore command first place in regard to benefits per dollar of expenditure. Loss of fish life in the main river valleys is in this way largely compensated for by ease of maintenance of fish life in the large lakes artificially created. There is obviously a vast

[12] Prepared by Malcolm Pirnie, consulting engineer, New York, N. Y.

field of construction open to employ large numbers of future generations in works to regulate stream flow which will be a substantial contribution to a steady rise in our standard of living.

Wastes from certain industrial developments are serious sources of pollution for many waters. The principal industries in the order of extent of interference with water supplies are: First, coal-mining washery wastes and acid drainage from abandoned and operating coal mines; second, coal distillation gas and coke manufacturing; third, metal pickling and galvanizing; fourth, chemical manufacturing acid wastes, oil and salt water from oil wells, and sulphite wastes from wood-pulp mills; fifth, tanneries and washing, bleaching, and wood distillation industries; sixth, sawdust from sawmills; seventh, textile industries using washing, bleaching, and dyeing processes; eighth, mining ore washing and tailings, munitions manufacturing, beet-sugar refineries, and combinations of various industrial wastes and sewage. All are producers of essential products. To eliminate some of these wastes would require elimination of the products and impoverishment of thriving communities entirely dependent upon these industries. However, substantial reductions in pollution will result from efforts to seal and flood abandoned mines, to burn sawdust, to recover and burn floating solids and to remove for recovery of byproducts such concentrated waste as can reasonably be handled in this way, but industrial wastes must continue to be discharged and ultimately to enter rivers and tide waters as the final drainage elevation.

Accepting the fact that the rivers are the main surface drains of the Nation, it follows that they must carry at least all of the soluble wastes of life and industry on their drainage areas. Future dedication of sections of selected main drains for the unavoidable gross pollutions of certain industries may be accomplished by zoning. This might prevent unwarranted increase in present pollution near headwaters of streams and carried out in step with works to increase materially minimum flows of streams, would produce a permanent improvement in the quality of the water in them. Public water supplies drawn from main drains should, when economically justified, be abandoned in favor of storage developments on lateral drainage streams. Partial removal of the organic load in sewage may prove sufficient present treatment for a majority of growing communities, the extent of removal of the organic load being increased in proportion to the increase in volume of sewage. Many communities now causing objectionable pollution of rivers during dry weather flows can continue disposal by dilution for many years if regulating reservoirs are built and operated above them.

The effective solution of the multitude of problems involved in sewage and sewage disposal requires that such works be classified in the order of greatest benefits per dollar of expenditure and proved best technological procedure at the time of undertaking each remedial measure. There is here room for extended and continuous research and for the employment of great numbers of future generations in the planning, construction, and operation of the needed public works. Long term programs of improvement of main drainage basins are essential to economies and sustained progress in execution. For example, the proper Federal agencies could cooperate with similar agencies of industry and the States and their political subdivisions to define the scope of the problem of pollution and to formulate a definite plan and schedule of construction equitably apportioned. With such cooperation progressive improvement in the quality of the waters of the United States may be accomplished.

Airports and Airways [13]

Air transportation has grown tremendously in the last decade, changing the traveling and mailing habits of many persons. Airplanes in operation have increased from 2,740 in 1927, the earliest year for which complete statistics are available, to 9,167 in 1936, and the daily average of miles flown by the air lines from 16,083 to 212,851 over the same period. Adequate airports are as necessary to the development of this mode of transportation as are roads to automobiles and roadways and terminals to railroads.

The increase in size of air transport planes with the resulting increase in gross weights, has rendered obsolete the old-fashioned landing field covered with sod, due to its inability to serve for all-weather operations which is one of the basic requirements for every landing facility designed for transport purposes. Major airports serving interstate, transport, and mail planes, now require at least a three-directional runway layout with each runway not less than 3,500 feet in length at sea level and 150 feet in width. These runways must have clear approaches within gliding angle of not less than 15 to 1. The surfacing of runways is of major importance. In their construction, machinery such as tractors and scrapers is utilized, as well as conventional paving materials such as cement aggregates, various types of tars, asphalts, and road oils in addition to steel for reinforcement purposes. Drainage, in most cases, is accomplished by the installation of drain tiles of clay, concrete, or metal as well as broken stone or gravel.

[13] Prepared by the U. S. Bureau of Air Commerce.

Modern air terminal facilities must include also proper housing, servicing, shop facilities, adequate lighting including boundary and runway lighting, provisions for flood lighting of landing area, and buildings on the airport proper, obstruction lights, and telegraphic and radio communication facilities.

For the identification of an airport, a rotating beacon is generally mounted on a tower equipped with code flashes blinking an identification code signal; illuminated roof signs also usually spell out the name of the airport. Marker lights include a series of white boundary lights mounted on sheet-steel cones. Obstruction lights also fall under the classification of marker lights and consist of red lights placed on or adjacent to all obstructions within a glide of 15 to 1. The most elaborate and costly part of airport lighting is the provision of flood lighting for the landing areas. Areas from 3,000 to 4,000 feet in length and 500 feet in width must be lighted, and this light must come from behind or from the side of the plane landing or taking off, necessitating, in most cases, several sources of light and controlled individually at the option of the operator. Direction and approximate strength of the wind are indicated by illuminated wind socks and lighted wind tees. At some of the larger and busier airports, approach lights of high intensity are being located outside of the limits of the airport indicating the direction of approach.

A special effort has been made to further the use of seaplane and open water flying by the development of a new seaplane ramp of the marine railway type. Landing floats and passenger facilities, together with service facilities for seaplanes have also been developed. Many of the larger cities along the Atlantic seaboard, the Pacific coast, and the Great Lakes region are today taking advantage of this plan.

The total number of airports and landing fields (including municipal, commercial, and private airports, Department of Commerce emergency fields, auxiliary, Army, Navy, Marine Corps, National Guard, and miscellaneous fields) has increased from 1,036 in 1927 to 2,402 in 1936. Approximately one-half of the 1,244 municipal and commercial airports, included in the total number for 1936, are provided with the technical facilities required for the type and volume of air traffic handled. The Bureau of Air Commerce and the Works Progress Administration now are cooperating in a program in which many new fields are being established and existing airports improved and modernized. Another development of the future will be radio and other assistance for landings in adverse weather. All indications are that air transportation will continue to grow rapidly and will continue to require further technical improvements in airport construction and a wider provision of such facilities.

Highways [14]

Historically, highway construction is one of the oldest construction fields. From the technical standpoint, however, it is one of the newest, for it is only within comparatively recent times that technical knowledge has been intensively applied to the solution of the various problems which it presents. A great deal of progress has been made but many problems remain and more are constantly arising.

The highway is essentially a traffic lane and as such it renders complete service only as it completely serves the needs of the traffic that passes over it.[15] From the design standpoint, this means, as to automobile traffic, the provision of facilities for speed with comfort and safety, and as to truck and bus traffic, adequate width, and adequate carrying capacity with freedom from excessive adverse grades. Technical advances in highway design to meet these objectives have involved some increase in average pavement thickness, wider traffic lanes, which, as compared to the width of 7 feet accepted as entirely adequate 20 years ago, are now seldom made less than 10 feet, with 11 feet increasingly common. Almost no modern highways are now built with less than two traffic lanes. Three-lane and four-lane trunk-line highways are common wherever traffic is heavy. Even six-lane and eight-lane highways are not unknown. The most recent improvement in design at this point involves the use, on four lane and wider highways, of a park area in the middle of the highway to separate the traffic moving in opposite directions. Greater safety is the objective. This is also true of the increasing use of nonskid surfaces which are now a common, almost a standard, feature in highway design.

Again, to promote speed with safety, alignment has been improved by eliminating curvature, and sight distances have been and still are being increased by using longer vertical curves and less abrupt changes in grade as well as by using fewer curves and curves of longer radii. Curves are superelevated wherever necessary and compensated on heavy grades. The ruling grade is being steadily reduced in the interest of truck traffic and the amount of rise and fall reduced.

Off of the surfacing itself, shoulders are being generally widened and given more load-supporting capacity. Side slopes are being reduced with a tendency, again in the interest of safety, to reduce the depth of side ditches. Clearances on bridges and culverts have been increased.

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[14] Prepared by J. L. Harrison, Senior Highway Engineer, U. S. Bureau of Public Roads.

[15] The transportation aspects of highways are discussed at some length in the chapter, Technology and Transportation.

To promote the pleasure to be obtained from recreational driving, thoroughly modern design includes such treatment by way of beautification through revision of the general cross section as may be required. It also includes grassing and whatever planting of creepers, shrubs, and trees as may be required to make the roadside itself pleasing, and to screen off objectionable and definitely unpleasant (off right-of-way) views. The modern highway designer also overlooks no opportunity to place his highways so that the beauties of the landscape are as fully revealed to those who use the highway, as may be possible without conflicting with other important design considerations.

In its broadest aspect, advancement in design is advancement in system planning. Here the modern concept is that the normal flow of traffic locates the highway. To state this matter a little differently, in system design, highways are planned and their capacity dictated by the free and untrammeled desire of traffic to move. A trunk-line highway is built, for example, between New York and Philadelphia because traffic in large volume wishes to move between these two cities. The highway is to serve, never to influence, this movement. It follows quite naturally that the highway system is the systematic development of facilities—highways—which harmonize with the desire of traffic for freedom of movement. Progress in the development, and in the expression of this concept is one of the outstanding achievements of recent years in the highway field.

From the materials standpoint, technical progress has consisted largely in the development of more complete knowledge as to how materials that have been available and have been used for thousands of years could be used efficiently and with greater certainty as to attainable results. Technical advancement has also involved and continues to involve progress in the use of such materials as cement, asphalt, tar, and steel to produce stronger, smoother, and more durable highway surfaces. The technical advancement which has taken place in the materials field has thus enabled engineers to use available materials with increasing confidence, to build more durable surfaces, and to provide a quality of surface and a freedom from the nuisance of dust and mud all but unknown until within comparatively recent times.

Technical changes in highway-construction operations hinge around the steady progress toward mass production which has taken place during the past 15 years. Larger and larger machines have so completely replaced the shovels, the wheelbarrows, and the carts of only a few years ago, that few industries can today boast of a more completely "machine made" product than modern highways. The modern power shovel, as used on highway work, takes out a cubic yard or more of material at a time more easily than the laborer of 25 or 30 years ago pitched his 5-pound load into the nearby cart. One man on a modern mixer mixes more concrete in a minute, and does it better, than a dozen men on a mixing board could 30 years ago in 10 times that period. The truck and its 5 to 10-ton load has replaced the cart which did well to move a ton. The modern hydraulically operated scraper carrying 8 or 10 cubic yards of material is moved more rapidly and more dependably than its ancestor, the slip scraper, which seldom carried as many cubic feet of material. These are but a few illustrations of the technical advancement that has taken place throughout the highway construction field, larger and larger machines, standard methods, mass production.

From the social standpoint, the changes which have taken place in the highway field have produced several important results. Mass production has meant less manpower used per unit of work performed with a steady reduction of unit cost to the public. During the 10 years prior to 1933 the drop in the unit cost at which highway work was being done was pretty steady and quite uninterrupted. It was somewhat accentuated by the depression and from the depression lows there has been some recovery. However, the over-all effect of the trend toward mass production has been definitely to reduce cost and definitely to reduce the demand for human labor per unit of work performed in the highway-construction field.

On the other hand, the trend in design has been toward the use of higher standards which with equal uniformity have resulted in the use of more and more units of work per mile of pavement laid down. Thus, in the modern highway more and more dirt is moved per mile, and more pavement laid. Bridges and culverts are wider. There are more miscellaneous structures. Advantages in unit costs and reductions in the amount of human labor required per unit of work done have thus been offset by the additional amount of work required. The net result has been that the cost per mile of highway and the demand for human labor per average mile constructed have not changed very greatly. On the other hand, there has been a vast change in what the public receives for the money it expends. The technical advancements which have been made in the use of materials, in design, and notably in construction methods are, in effect, constantly placing smoother, safer, more durable, more dependable, and more beautiful highways at the disposal of the public without additional cost.

Future Outlook [16]

Technical progress in construction for many centuries was determined by fortuitous circumstances, and the slow handiwork of skilled artisans. During the past 70 years, however, it has increasingly responded to scientific analysis. Today such analysis by trained engineers and architects dominates the design of works and structures other than houses; plays an important part in the improvement of materials and equipment, and within the past 15 years has more and more determined the methods used by contractors and others in actual field operations. This situation has greatly advanced the rate of technical progress and is likely to continue to do so in the future.

Many striking illustrations of the introduction of the scientific method in construction during the past few years are described in the preceding sections. One of the most spectacular advances in design is the use of polarized light together with models of isotropic materials such as celluloid in the analysis of internal stresses in structural members of irregular shape. X-rays have also been used quite recently for the internal inspection of welded connections. Methods of analysis are also available for determining the deformations and stresses in small-scale models of large and complicated structures. The physical characteristics of soils under pressure have only recently been subjected to rigid analysis. Conspicuous improvements in the properties of both ferrous and nonferrous metals have also been made possible by recent advances in metallurgy. Some of the newer types of plastic materials made from cellulose or from phenolic resins suggest many enticing although remote possibilities, such as the shaping under pressure or by casting in molds of complete wall panels, possibly of pleasing and enduring colors, for houses or other structures. Nearly all of these recent advances are the results of research in the fields of chemistry, physics, and mathematics. From a technical point of view, the opportunities for the future extension of many of these methods appear very great.

Influences Affecting Technical Change

The extent to which new developments are likely to be introduced will undoubtedly be determined, however, in an important degree by nontechnical factors. Some of these factors which logically are closely related to the trends in construction technology are:

1. The extent to which facilities for research are provided for investigations in the design and methods of fabrication of works and structures.

2. The quality and availability of scientific training to qualified students in colleges and universities.

3. The freedom afforded by the form of organization of private industry and by governmental agencies for the introduction and development of new processes.

4. The extent to which financial and other economic conditions may be favorable to long-time expenditures.

Research laboratories of the Federal Government as well as those of many universities, special government agencies such as the Port of New York Authority, and private corporations have contributed greatly to recent progress in the design of highways, dams, and bridges and in testing materials of construction. Construction, as has been observed, is to a large extent a nonduplicating industry. Technical progress comes both through scientific improvements in materials and through the skill with which fundamental principles are applied to the solution of engineering problems of particular projects.

A surprising number of the leading designers in this country in the past have been trained in the refined methods afforded by European technical schools and universities. The physical resources and productive energy of American governmental and private business organizations have enabled us to excel in the magnitude and number of works and structures actually built, but for many years we leaned heavily upon the methods of analysis developed in Europe. Refined methods, however, and the scientific character of professional engineering instruction have advanced considerably during the past 15 years in the United States. Unfortunately, the low levels of activity and employment in construction since 1930 have greatly discouraged the study of professional engineering although the proportion of students continuing with advanced studies has increased.

Actual construction operations by private agencies are, for the most part, highly competitive and provide considerable freedom for the introduction of improved methods. The extent to which such conditions may prevail in the manufacture of materials and in the design and construction of works and structures will have an important bearing upon the projects which will be technically and economically practicable.

The violent fluctuations in activity which have characterized many types of construction in the past, particularly private residential and commercial building, are unfavorable to technical progress. Technical methods, such as the shop fabrication of houses, requiring a substantial capital outlay are confronted by serious difficulties in an industry the demand for the product of which fluctuates as violently as has that for new dwelling units.[17] Furthermore, the un-

[16] Prepared by Lowell J. Chawner, Senior Economic Analyst, U. S. Bureau of Foreign and Domestic Commerce.

[17] The fluctuations in residential building are discussed more fully by the author in Economic Factors Related to Residential Building, Annals of American Academy of Political and Social Science, March 1937.

sound financing of the types of structures mentioned above, commercial and residential building, in which the financial instruments resting upon many properties were quite unrelated to the long-time rate of income and to the depreciation and obsolescence of such properties, was to a large extent involved in the complete break-down of the new capital market in 1932 for these types of buildings. Notable changes over the past 20 years have been made in the financing of farms and farm improvements by such agencies as the Federal land banks. Marked improvements in the financing of urban homes and of some large dwelling structures have also been made in recent years by the Federal Home Loan Bank System and the Federal Housing Administration. The practices in the financing of other types of real property ownership which are likely to prevail during the next decade are, however, not as yet well defined.

In addition to the possible development of entirely new methods and materials, some observation may be warranted upon the increasing adaptation to new uses of methods and materials already well known. Improvements in earth handling and soil mechanics and in rust-resisting steels which were largely developed for other uses may possibly see some further adoption in the construction of dams in the next few years. Recent improvements in low-heat producing cements also greatly enlarge the possibilities of the use of this material in the rapid construction of large dams. The tragic loss of life and property by floods throughout the eastern United States in the spring of 1936 and in the Ohio and Mississippi Valleys in January 1937 have called particular attention to the urgent need for control of the flood flows in many water sheds. Recent technical developments in construction during the past few years should greatly facilitate projects of this character.

Summary

In recent years technological changes in many types of construction have greatly enlarged the size of structures, have reduced the costs of some types of work, particularly highways, and have had notable effects upon the comforts and conveniences of both urban and rural life. The rate at which these changes have occurred has been increasingly rapid, particularly in the types of works and structures financed by public agencies and those in which research has been active. It is not readily determinable to what extent technical innovations may have favorably influenced the volume of activity or, on the other hand, to what extent sustained activity may have promoted the study of technical problems, thus resulting in gradual improvements. It is most likely that the two factors have been reciprocal in their effects.

The future role of technology in the character of its relation to construction will probably be much the same as it has been in the past. The rate of improvement, however, subject to a number of nontechnical factors such as social conditions favorable to research, to the adoption of new methods of design, and to the use of new materials, may possibly be more rapid. Many works and structures for transportation, flood control, housing, and the provision of urban utilities and services heretofore technically impracticable or requiring extensive expenditures may thus become technically available at reasonable cost. The present advanced position of engineering science and the prospects for its future growth support such an assumption. Certain economic and other social factors are less convincing. In either case the extent of the public interest in freeing and encouraging these improvements will largely determine in the next decade or more the technical progress which may be expected in construction.

This report was prepared under the direction of a subcommittee of the Science Committee. The latter group is made up of designees from the National Academy of Sciences, the Social Science Research Council, and the American Council of Education. These organizations assume no responsibility for the views and opinions expressed by their designees.

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